Congress of the United States
Office of Technology Assessment

TECHNOLOGY AND THE FUTURE OF THE U.S. CONSTRUCTION INDUSTRY

Proceedings of the Panel
on Technical Change and the U.S.
Building Construction Industry

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Technology and the Future of the US Construction Industry

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Foreword

The American Institute of Architects is pleased to publish this report in cooperation with the Office of Technology Assessment for the United States Congress.

The OTA panel on technology and the construction industry explored topics such as commercial building designs, energy use in buildings, and the future utilization of computers in the construction industry. While not endorsing all the views expressed in the report, the AIA offers the publication to foster discussion of the construction industry's future and the critical role of the design professions in shaping the built environment.

The American Institute of Architects is interested in hearing from readers of this report, and asks that comments be directed to the Office of the Executive Vice President at the American Institute of Architects, 1735 New York Avenue, N.W., Washington, D.C. 20006.

John A. Busby Jr., FAIA
President
The American Institute of Architects

1

Technology and the Construction Industry: An Introduction

Henry Kelly

Technology is reshaping the American economy. Vast improvements in agricultural and manufacturing productivity have outstripped demand to the point where net employment in these areas is falling while employment in business service professions has soared. Economic growth has been buoyed by enormous volumes of sales in office computers, telecommunication systems, and other products not even on the market a decade ago. Whether the rate of change is more or less rapid than it has been in the past, whether the changes are evolutionary or revolutionary, is in some ways not as important as the fact that, taken together, these changes have dramatically reshaped the way the economy combines material, capital, labor, and ideas to provide most kinds of goods and services. The work described below was undertaken because the chairmen of several Congressional committees asked the U.S. Office of Technology Assessment (OTA) to describe the way new technologies are acting to reshape the nation's economy. One of the areas chosen for special attention was the construction industry.

There is a widespread perception that the technologies that are reshaping most of the rest of the economy have left the construction industry behind — that Ramses II would probably recognize most of the operations in today's construction site. Construction is typically considered a low-technology industry operating in sheltered local markets with low or falling productivity. Believing this to be a mistaken impression, OTA convened a workshop of experts with direct experience in construction. The topics were selected after extensive preliminary discussions with industry experts who were asked to identify areas where technology was likely to have its greatest effect on the industry as a whole: the use of information technologies; factory construction techniques; new energy technologies; and new structural designs. Participants were a diverse group drawn from industry, academia, and government. The diversity of the participants was a reflection of a diverse and decentralized industry. Many of the participants met each other for the first time in the workshop even though they had spent careers studying different aspects of construction.

The construction industry, of course, is not really a single industry but a complex cluster of industries somewhat uncomfortably combined under a single classification. Residential construction, commercial buildings, industrial structures, and civil engineering projects are typically bundled somewhat uncomfortably together. Moreover, construction activities combine a wide range of different professions: architects; engineers; and specialists in site work, renovation, and maintenance. Different teams are formed for new projects. Teams assembled for major projects often disperse after the projects are complete. This fluidity and flexibility makes the industry dynamic, resourceful, and adaptable. But the diversity has always frustrated efforts to analyze the net performance of the industry as a whole. In fact, several of the workshop participants argued that while much of the industry's strength lies in its flexibility, excessive fragmentation can also create problems. Often, no one has a perspective on the construction process adequate to detect inefficiencies that result from imperfect coordination among the firms responsible for construction, or adequate to combine an analysis of construction decisions with an analysis of the implications of these decisions for building operation and facilities maintenance. The diversity also makes it difficult to measure progress in the industry since national economic statistics provide a poor picture of the diverse enterprises that combine to make the U.S. construction industry.

We asked the participants to explain how the technologies they knew best were reshaping the construction industry, and we asked them to speculate about the possible impact of the changes that might result on overall growth rates in the industry, the quality and performance of building products, the number and nature of jobs created by the industry, and the international competitive position of the domestic industry. The discussion also considered areas where optimum implementation of new technology may require a review of existing federal, state, and local policies that are used to regulate the industry. The policy consequences of new construction technology will be the subject of a separate study and are not extensively discussed in this volume.

The workshop established two points quite clearly. First, the construction industry is being reshaped, in some cases radically reshaped, by new technology — although the changes are seldom obvious to casual observers. And second, many attractive new technologies are being adopted slowly because of the industry's fragmented nature, the failure of clients to demand innovation (due in part to the fact that they seldom recognize the potential advantages of new technology), the shortage of research funding from either public or private sources, by a regulatory structure poorly adapted to rapid technical change, and fear of litigation. Slow rates of adoption of new technologies can make the industry vulnerable to foreign competition and rob clients of qualitative improvements in buildings that could not only make the building a more attractive place to work or live, but reduce operating costs as well.

The workshop was organized around the premise that technology affects the construction industry in three principal ways: (i) technology has reshaped the national economy in ways that affect demand for different kinds of structures; (ii) technology has changed the nature of the structure itself (including the services provided by buildings); and (iii) technology has changed the way that structures are produced and erected.

1. Demand

Even if it embraced no new technologies itself, the construction industry would be forced to change in response to the transformation underway in the the American economy. America is becoming a nation of office workers. This means greater emphasis on office structures. Moreover, the nature of office work is itself changing in ways that, in turn, are changing the demands placed on buildings. While we can expect significant growth in the productivity of production-floor operations, many of the most dramatic increases in national productivity during the next decade are likely to occur because of improvements in the technology of office work. This is as true for sales clerks, hospital employees, architects, lawyers, and teachers, as it is for insurance agencies and banks. Offices are becoming much more heavily capitalized as word processors and other more sophisticated computer terminals substitute for routine clerical work. This trend means new office designs and new demands on the building infrastructure. Moreover, modern communications give management much greater freedom to choose locations for 'back office' activities and a variety of other functions. There is seldom an absolute need to locate these facilities near central headquarters buildings or even near the production facilities that they may support. The result has been a decentralization of operations, suburbanization, and rapid movement toward the south and west.

We must also consider the dynamics of change. It is now clear that most buildings will need to be adapted to a variety of different purposes during their design lives. A fast-paced economy means increasing need for flexibility — particularly in office activities where it is simply impossible to predict what equipment will dominate ten years from now or, indeed, what equipment will be available next year. This means that structures dedicated to a single purpose, and structures that cannot be upgraded to accommodate modern communication systems and energy efficiency technologies, are increasingly unattractive investments. Some of the members of the workshop, most prominently Wendel R. Wendel, argued that we should try to move away from the notion that buildings are permanent monuments and recognize that the provision of shelter is a service —

a service that should be tailored to a need as long as the need lasts and then modified or retired.

Several of the participants suggested that buyers' standards and tastes may be changing in a way that affects the market for buildings in qualitative ways. Buyers may become increasingly intolerant of uninteresting structures, or structures that do not create a pleasant work environment. The relationship between the work environment and workplace productivity has received particular attention. James Gross notes that the total wages and salaries paid to people working in a building is an order of magnitude higher than the cost of the building itself. Anything that can increase the productivity of the occupants is therefore likely to be a wise investment.

2. The Structure Itself

a. The 'Smart' Building. The construction industry has responded to changing demands by modifying both what is built and how it is built. It is becoming difficult to know what we mean when we talk about a 'building.' Surely we must include the basic space-conditioning and lighting equipment. Presumably, we also include the systems that operate elevators, security systems, and other equipment key to basic operation of the building. It seems reasonable to include the complex computer systems that are now managing lighting, chillers, and other energy systems. But should other features that come under the broad concept of 'smart buildings' be considered a product of the construction industry? For example, with the breakup of AT&T, telephone wiring should probably be treated in the same way we have treated conventional electrical wiring. Should we also include the more sophisticated infrastructure needed to operate office automation systems: antennas on the roof; fiber-optic cables; computer centers that may perform telephone switching, broadband communication, and data management functions, as well as operate security systems, energy systems, and elevators? How should we treat furniture if the furniture becomes a critical part of the office environment. In many cases, for example, it may be better to make lighting fixtures a part of movable partitions instead of making them permanent fixtures. While 'shared tenant services' have not fared well, the difficulties may lie more with the institutional arrangements offered, and inattention to the real business needs of customers, than with the underlying capabilities of the technology. Relationships between building owners and tenants are likely to change in ways that blur the formerly clear distinction between the building shell and the apparatus introduced into the building by tenants. At a minimum, a premium will be placed on structures that can flexibly adapt to changing needs of tenants. Structures may provide fewer 'built-in' services and tenants may be expected to provide more for themselves. Tenant-supplied lighting, for example, is much more likely to be efficiently matched to particular needs than systems designed to provide the entire building with lighting levels high enough to satisfy the most demanding draftsman. (The advantage of avoiding fixed lighting systems is underscored by the fact that the next generation of draftsmen is likely to want lower-than-average lighting levels in areas where they will be looking at display screens instead of fine print on paper). On the other hand, buildings could provide more services, making building owners, in effect, service companies that offer such things as computer and communication services, along with 'basic' utilities like electricity and heat. Unfortunately, national data is inadequate for measuring the extent to which these new technologies are actually being introduced in new structures. The most impressive examples of 'smart building' concepts have been in proprietary structures.

Leaving aside the revolution in the technology of office work, there are also major changes underway in the technology of the basic structure. The materials used for building components have also changed. Plastic pipe and steel studs are easy to see, but a variety of other new products are being used in insulating materials, floor coverings, exterior wall surfaces, glazing, and floors. Technology has challenged conventional notions about how to provide basic structural support. Optimum design engineering has refined conventional designs. Truss systems, such as the one marketed by Space Structures, can vastly reduce the cost of large, unsupported spans. A variety of new adhesive materials are used to attach everything from decorative paneling to structural members.

b. Building Operations. Building control technologies must also be considered as part of larger systems that are themselves 'smart.' Thinking about this issue requires a consideration of the 'life-cycle costs' of structures including an analysis of operating costs and the costs associated with making modifications that will be needed during the structure's useful life.

Energy

The energy price increases of the 1970s resulted in an explosion of new ideas for improving the efficiency of energy use in buildings. New residential and commercial buildings can be built which use a fifth as much energy per square foot as comparable structures built during the early 1970s. Some of the improvements are straightforward — improved insulation, for example. Some result from a better understanding of heat-flows in structures. And some result from clever new equipment and control systems. A flood of highly efficient furnaces, air conditioners, lighting equipment, and other appliances has been introduced during the past few years. Many are several times more efficient than the equipment they are designed to replace. But while component improvements provide important new tools, their full value can only be recognized if they are used as a part of an integrated analysis of building energy that includes an assessment of the dynamic performance of a building's shell. Overall levels of savings can be remarkable. The code likely to be adopted as an industry standard in 1986 recommends levels of energy use that are less than half the levels typical of the early 1970s. The savings are not achieved from a single 'breakthrough' technology but rather from the combined effects of a large number of improvements in structural designs, equipment, and control strategies.

Integrated analysis of energy use should probably include an assessment of the way buildings operate as a part of regional networks. Equipment capable of integrating the energy management controls of individual structures with the dispatch controls of electric utilities can significantly improve the dynamic performance of electric networks taken as a whole. Experiments are already underway abroad and in the U.S. by which utilities can continuously vary their electric rates according to an instantaneous estimate of marginal costs of production, and can transmit this information periodically to buildings of all kinds (including residences). Control systems in each structure can respond to these price signals by adjusting the performance of equipment in prearranged ways. The response can be as simple as postponing the start of a water heater or chiller when prices exceed some threshold level. Dynamic control over demand can allow utilities to meet a larger fraction of total electric demand from relatively inexpensive 'base-load' plants using coal or nuclear fuels.

Sophisticated new building technologies are, in a very direct way, substitutes for electric generating technologies. Trade-offs between investments in new generating capacity and investments in buildings are not a trivial matter. More than two thirds of all electricity in the U.S. is consumed in residential and commercial buildings — most of it for commonplace purposes: lighting, refrigeration, and air conditioning. Improved analytical tools, coupled with a few technical tricks, have permitted vast reductions in the amount of energy required to heat and cool a building. Changes range from reprogramming air-handling systems, to the development of high-technology light bulbs. Taken together, they can reduce the net energy consumption of typical residential or commercial structures by factors ranging from two to ten. Effective use of these new technologies will require an approach to electric utility management that allows potential investors to make an unbiased comparison of investments in electric generation and investments in technologies that make efficient use of electricity in buildings. Several workshop participants noted that the existing system badly biases decisions, since the financing available to regulated utility monopolies (allowing investments with twenty-year paybacks) is much different than the financing available for entrepreneurial investments in buildings where annual returns of 100 to 200 percent are expected on investments in building efficiency.

Facilities Management

The issue of facilities management and building operations has about as much sex appeal as a week-old cheese sandwich. But the issue has taken on growing importance as demands for building modifications increase as a result of the increasing volatility and uncertainty in demands for residential and commercial space — including changing interest in the energy consumption of buildings. Facilities management can be greatly simplified by using computer-based drawings and records of the kind that will be discussed in greater detail in the next section. A set of digital 'drawings' of a building that can be conveniently updated after each building modification greatly reduces the uncertainties and costs of structural modifications. There is less trepidation as you drill through a wall (famous last words: "Where did they put the high-voltage cable?"), and there is less need to track old Fred to his trailer in Florida so that he can explain what he meant by the note scrawled on the margin of the original drawings. A continuously updated building design can also facilitate analysis of changes in structures and heating and air-conditioning systems.

3. The Construction Process

Turning to the question of how structures are actually made, three themes seem to dominate: (i) improvements in the process by which an idea goes from a gleam in a designer's eye to a set of working drawings; (ii) greater use of factory-based construction techniques; (iii) and use of more sophisticated equipment in the field.

a. Design. New computer-based systems can improve the productivity of building design and analysis. They can rapidly convert concepts to drawings, convert drawings to analysis and convert all of this to estimates of initial costs and operating costs. The systems can be used to prepare working sketches and detailed drawings. Routine building components (repeated window and door treatments, for example) can be called from digital files that need be entered only once by a draftsman. The equipment thus substitutes for the most tedious aspects of drafting. Price lists can be built into the systems, allowing an instantaneous estimate of the cost of different design alternatives. Advanced systems allow a computer-based 'tour' of building interiors and exteriors. Once entered, the design information can be used as the basis for computer-based structural analysis, an analysis of lighting, or an assessment of energy consumption.

Many architects, however, greet the prospect of computer-assisted design with the enthusiasm of a cat facing a pail of water. Their perception is that computers will substitute mechanical decisions for taste, and formulas will be substituted for inspiration. All this is plainly possible. But increasing competitive pressure for speed and cost control make it extremely difficult for the **average** architect to produce an **average** building with much imagination, unless there are some fundamental changes in the design process. Computer-assisted design systems may enable such changes. While the full potential of the systems is unknown, it is apparent that the systems can remove many barriers between inspiration and execution. They can improve communication between designers and their clients, allowing vastly more 'what if' excursions and discussions about options at different levels of investment. There is no good way to calculate the benefits of greater client satisfaction, but surely improvements in this area are among the most important contributions a new technology can make to the construction process.

Computer-based technologies can significantly reduce the cost of making modifications to existing plans while preventing errors from creeping into areas unaffected by the change. The penalty for trying a radical new idea can be reduced since the concept can be subjected to a detailed analysis, and reduced to drawings that permit a realistic feeling for exterior views and interior spaces without a major investment in time or money. Automated design systems coupled with communication systems can facilitate the performance of geographically dispersed teams, allowing clients, engineers, construction firms, and architects to cooperate effectively during the evolution of a design. They can facilitate the process by which specifications are sent out for competitive bids, reduce the uncertainties associated with bidding, and decrease the burdens associated with the submission and analysis of proposals.

Once the basic design has been entered into a computer-based system, a variety of analytical programs can use the data to assess such things as the energy-consumption consequences of different design decisions. Until now, one of the greatest barriers to energy-efficient building designs has been the fact that heating, ventilating and air conditioning (HVAC) analysis is typically conducted after it is too late to change any major feature of a building's basic design. There is also a considerable 'pain-in-the-neck' factor involved in submitting drawings to a specialized group for energy modeling. It is tempting to hand completed drawings to an HVAC engineer and say, "Just make sure it doesn't overheat."

Design flexibility is not limited to commercial structures since it is now relatively easy to offer prospective home buyers the opportunity to design their own floor plans, and compare the appearance of different interior and exterior wall coverings in the spaces they have designed. Though only a fraction of new houses are designed with the help of an architect, it is possible that the new systems may permit prospective home buyers greater flexibility in selecting and refining home designs, using the services of an architect, at least indirectly in the form of skillfully designed software. The Japanese have a system in place for doing this that is connected directly to production equipment capable of delivering preassembled units to a construction site in two to three weeks.

b. The Construction Process. If computer-assisted design is the first major revolution in the making of buildings, factory construction is the second. Construction has always been something of a craft, with each structure fabricated from basic components in the field. The literature is replete with predictions that this primitive form of fabrication was about to end and the industry would evolve in a way that would make it more like conventional manufacturing. A commission organized for Franklin Roosevelt in the mid-1930s made this claim. Truman appointed a 'housing expeditor' who was determined to solve the housing shortage at the end of the second World War with factory-built housing. Only a fraction of the goal was met. George Romney rekindled the dream a generation later with his 'operation breakthrough,' which similarly fell far short of its goal. When forecasters have a track record like this, it is easy to be cynical about new claims. But we may have become so cautious that we may not have noticed how far, and how fast, we have moved toward factory-based construction of homes and small commercial structures.

No one in the workshop challenged the estimate that nearly half the homes built today involve a significant amount of factory construction, with the other half making very heavy use of factory-built components: roof trusses, pre-hung windows and doors, 'wet-cores' (bathroom and kitchen units), and the like. In Sweden today over 90 percent of all new houses are made in the factory. Is our industry headed in the same direction?

One of the barriers to factory construction has always been its association with inexpensive, monotonous 'pre-fab' construction. And indeed, drab, low-quality houses and mobile homes have been produced in factories. In Sweden, on the other hand, factory-built structures are considered to be of a higher quality and have a higher status than site-built homes.

Factory construction offers several clear advantages. It permits uniform assembly, testing, and inspection. It permits relatively rapid on-site erection, thereby reducing constructing financing charges. It permits the use of more sophisticated assembly equipment. And it permits the kind of design flexibility described earlier. Of course, not all, or even most, of the opportunities are exploited in existing fabrication facilities.

The new technology is, of course, not without some drawbacks. Movement to factory construction could undermine the position of some small businesses, eliminating jobs or replacing skilled jobs with relatively unskilled ones, and weakening the role played by local regulatory authorities. The next section will return to this issue.

Field erection techniques are also in the process of rapid change, particularly for commercial structures. A variety of computer-assisted equipment has been introduced in the past few years. It ranges from earth-handling equipment to erection cranes and fully robotic equipment. Computer-assisted equipment is being introduced for two primary purposes: replacing people in hazardous circumstances, and improving precision. A significant fraction of construction accidents, for example, result from crane operations. It is apparently rare for a crane operator to complete a career without being involved in a fatal accident. Control equipment can automatically 'remember' critical lift heights and swing restrictions. Earth-loading equipment can be programmed to dump only after sensing a truck in a proper orientation.

One of the major barriers to increased construction productivity has been the difficulty of making joints. Accumulated field errors often result in joints that fall far short of specified tolerances. It is difficult to introduce precisely engineered components in a project where overall standards of precision are lax. Productivity gains require all components to be erected with roughly the same standards. Precisely engineered components, such as the computer-constructed, space-frame structures, for example, must frequently be adjusted to fit imprecise structures. Errors of as much as a foot are apparently common in structures of ten stories or more. Improved grading equipment, guided by laser leveling and positioning equipment, is an early example of devices designed to improve the accuracy of field work. In the near future, computer-assisted equipment with active location controls can further improve the precision of field work.

A final field that defied the analysis of the assembled experts had to do with the technologies of renovation and retrofit. Statistics on the size of these enterprises are particularly poor. But it is reasonable to argue that rapid improvements in building technology will increase demands for building renovations to improve the large stock of existing structures. While some new technologies are available for diagnosing and repairing problems identified in older structures, the field remains a very murky one. Most of the new techniques identified were designed to pinpoint sources of heat leaks so that the energy efficiency of the structure could be improved.

4. Impacts

a. Employment. Taken together, how will new technologies change the construction industry, the quality of the products it delivers, and the nature of the jobs it offers? There is little question that the technologies described have the potential to affect both the number of jobs generated by the construction industry during the next decade, and the nature of these jobs, in dramatic ways. On the whole, it seems likely that the net labor productivity of the system can be increased, though experts disagree about the quality of the jobs that will remain. No one has a satisfactory explanation for the mysterious fall in the productivity of the construction industry measured using standard statistical series. Some of the workshop participants claimed that the decline was an artifact of flawed measurement. The productivity gains created by modular-home factories, for example, do not contribute to the measured productivity of the construction industry since factories are classified as manufacturing firms and not construction companies.

Design firms are likely to see routine drafting and cost estimating become much more productive as modern equipment assumes a greater portion of routine chores. There will be fewer people as well as fewer steps between the designer, the engineer, and the customer. The opportunity to keep refining and revising designs, and the opportunity to try relatively imaginative designs at modest cost, may keep overall levels of employment relatively high even though the productivity of each individual analysis may have increased. Certainly this has happened in other 'office-automation' settings where the demand for new information and data has outstripped growth in the productivity of generating data.

Factory construction can also reshape construction trades. The technology can be used to replace skilled field labor with relatively unskilled, routinized jobs in assembly lines. Flexibility in these settings has too often been achieved the easy way — by laying people off when business slows. But technology can also be used to create for production workers relatively attractive, indoor jobs which are less subject to the vagaries of weather. Workers in the construction industry could then be treated more like employees of an automobile fabrication facility than day laborers, with greater opportunity to acquire new skills as new technologies are introduced, more continuity of employment, and better identification with a firm.

b. Education. There is little doubt that the new building technologies place new burdens on the educational system. At first the demands seem contradictory. There will be a need for individuals with highly specialized skills and a need for individuals with a broad perspective on many aspects of the design and construction process. In fact, the underlying demand is for individuals with basic skills in architecture, engineering and analysis who can quickly acquire specialized skills when needed. Lighting design provides a particularly vivid example of the need for unique combinations of skills. Good lighting design requires knowledge of such diverse areas as fixture technology, control systems, and daylighting strategies.

There is an obvious need for architects and engineers familiar with the capabilities of computer-assisted design and analysis techniques. Architects will need to know more about engineering, and engineers will need to learn more about design. There are growing demands for individuals who understand how to analyze heat-flows in buildings, optimal dispatch of electrical equipment, and the capabilities and limitations of the variety of new materials. And there is an interest in individuals able to work as effective members of a multi-disciplinary team.

c. Industry Structure. What will the technology do to the structure of the industry? Will we see engineering firms displacing architects? Will smaller design firms be edged out by large firms capable of mastering expensive new computer technology? Will factory construction change the role of the small, independent homebuilder who has been the mainstay of the industry for centuries? Will the small builder's role be largely one of site preparation and assembly of components manufactured by larger companies?

Several of the participants argued that engineers will play an increasing role in the design of buildings, citing examples of architecture and engineering firms that had become engineering and architecture firms. There is no reason why the engineers should run away with the show. To maintain control, however, architects must master the art of gracefully integrating engineering analysis into their designs. Computer-based systems may provide a good opportunity for doing this.

The cost of powerful design equipment is falling so rapidly that most small firms will be able to purchase quite sophisticated computer-assisted design and analytical systems within a few years. Thus, most members of the workshop felt that small design firms would not be threatened. If nothing else, the dynamic nature of the industry is conducive to small, relatively specialized firms that can be combined for specific projects.

The role of the small builder, on the other hand, may well change if factory construction captures a growing share of the market. Growing use of factory-made structural elements has already made the small builder more of an assembler than a craftsman, a trend that is likely to continue. Will the small builder's role be limited to pouring a foundation and assembling a set of modules or panels? Will he become a captive of major production houses? The experts disagreed on this point.

d. The Dynamic Performance of the Industry. Will all of this new technology and the pressures of foreign competition lead to a permanent shift in the way the construction industry conducts research and adopts innovations? At present, the evidence is somewhat ambiguous.

While there was one strong dissent, most members of the workshop were concerned by the shortage of research money in construction. Virtually all research is conducted by component suppliers and not by the building industry itself. Chemical companies, for example, have developed new materials for sheathing, roofing, piping, and adhesives. But research on components is not an adequate substitute for research designed to improve the way the building performs as an integrated system or the way the construction process operates as a whole.

The largest U.S. home builder apparently has no research budget. The professional associations of builders and architects have research budgets that are tiny in proportion to the industry they support. The National Institute for Building Science has an extremely small research budget. Direct government support for building-related research funded through HUD, the Department of Energy, and the Bureau of Standards was never very large and has been drastically reduced in recent years.

Failure of construction firms to conduct significant amounts of in-house research can lead directly to a relatively slow rate of growth in construction productivity. It can also have strong indirect effects. Studies of manufacturing firms show that firms with significant amounts of in-house research are in a much better position to monitor research conducted by other firms and are much better able to exploit new discoveries and innovations.

Two other major American industries share the problems of the construction industry. The health industry and the agricultural industry consist of relatively large numbers of relatively small establishments and firms — few of which have the resources to conduct their own research. In both cases, the government has chosen to support such research. For reasons of history, construction is treated quite differently.

5. Where Do We Go From Here?

It is clearly possible to use new technology to provide interior spaces that are more productive and more comfortable, without significant increases in cost. New technologies allow the construction of structures that are more flexible, more free from defects, and less expensive to operate. Unfortunately, it is also possible that foreign construction firms will move more rapidly to exploit these opportunities in U.S. markets than will domestic firms.

The technologies of 'smart buildings,' computer-assisted design, and factory-construction techniques open a range of promising business opportunities. One of the most fascinating is the possibility of managing buildings as business-service companies capable of providing everything from comfortable and flexible office space to advanced communication networks and 'value-added' computer systems. The industry is clearly capable of delivering superior products where they are needed. But institutional problems, and an antiquated set of federal, state and local policies, may make it difficult for innovators in the industry or their potential customers to exploit the possibilities.

2

Computers and Construction
Harry Mileaf
Alton S. Bradford

Harry Mileaf

Slow Computer Use In Construction

I've been studying the construction industry's involvement with computers since 1979, and have done so in over twenty surveys. Each survey dealt with samples that measured in the thousands. The results of each survey and their cumulative trend analysis have led me to be somewhat *conservative* in my *near-term* forecasting. The studies have repeatedly shown that there is no revolution taking place. Progress and changes have been evolutionary, and will continue to be so in the near term — during the rest of this decade. There are some prognosticators in our industry who have been much more *liberal* in their forecasting, anticipating a revolution in the industry in the not-too-distant future. I agree that revolution will come, but not in the near term. The evolutionary process will continue until after the mid 1990s, when the cumulative effects of computer use by the various influences in our industry, as well as the greater sophistication of computer systems at that time, will speed up the evolutionary pace to that of revolutionary proportions, if left unchecked. Evolution can be controlled, revolution cannot. There is the potential that by the year 2000 a major dislocation can occur in the design industry.

By the end of this decade over 90 percent of the design firms say that they will be using computers. This sounds like this alone will have a major impact on our industry; but, it probably will not, because of what the computers are being used for, and the projected growth of these uses.

The average firm that uses computers has barely scratched the surface of potential applications. The tendency is toward four or five *rote* applications, those applications that are easiest and most inexpensive to get started with, and which appear to have quickest productivity gains: word processing; spec writing; accounting; number crunching. There is little integration of these applications, almost no data base activity, and very slow growth in meaningful graphic design systems. What little is being done with sophisticated graphic design systems (about 7 percent with the small firms and about 12 percent with the large firms — 8 percent overall) is almost limited to drawings not design. This seems to make sense because drawing production is where the major labor effort is in a design office. But productivity gains in this application are scattered and many times unattainable. Even if the productivity gains were attainable, the gain would only show up for the specific projects being worked on. Even with a firm that is heavily involved with computers, only a small percentage of project work is handled by computer. The majority of work is still being done in the age-old, traditional, manual manner. This is why, even though computers have become commonplace in the design profession, they have had little impact on the profession. A staff of thirty sharing one terminal, or a staff of fifty sharing three, or a staff of two hundred and fifty sharing thirty will continue this low impact.

Why Is This?

Even the computers of today do not have the abilities to fulfill the promise of tomorrow. The computers still rely too heavily on the availability of individual applications programs to accomplish individual tasks, and both the hardware and software are still too expensive to put the entire staff at the keyboard. The great advantage of the computer comes from the computer taking over a task and completing it without human intervention. The so-called automated spec writing systems of today are not really automated, but merely mechanized versions of the old cut-and-paste method of spec writing. Too much human interaction is still required. The same is true of the so-called sophisticated drawing systems, and the other specific-task activities being done by computer. As long as the computer continues to merely mechanize the individual tasks with the help of human operators, and particularly without the tasks and data being integrated, progress will continue to be slow.

But We Cannot Be Misled By This

The improvements in the capabilities of computers over the last five years have been immense, and their drop in prices, remarkable. These improvements will continue, likely in an accelerated way to the point where their use will have a dramatic impact on how design offices function, and will likely change the way the entire industry functions. But when?

The specific applications computers of the past and present, which rely on complicated expensive programming, are already evolving into *expert* systems, systems which are not only developed by experts in your field, but which also contain data bases of expert knowledge. Such systems will require less and less complicated specific-task software written in expensive code language. The user's dialogue with the computer will be in straightforward English. Some systems of this type are already being used successfully in other industries. By the end of this decade, expert systems will be a growing force in the construction industry.

Concurrent with expert systems, artificial intelligence systems are receiving a good deal of attention in the academic world; and in the Japanese computer industry, it has become a national effort to make it a realization in the early '90s.

And There Is A New Force In The Marketplace

The new force is the client, the one who funds the new construction. Clients are changing. They are becoming more and more sophisticated. They are starting to computerize more rapidly than the construction designers. Even CADD vendors recognize this, and have diverted much of their efforts from the slow-buying construction designers to the corporate world. Business, industry, institutional, and public sector organizations recognize that CADD use in facilities management represents a good investment. Facilities management, which was heretofore a heterogeneous practice is becoming more organized; and corporations getting CADD systems are starting to lay their construction plans around facilities management data bases. Clients are gaining much more knowledge and are building confidence and relying less on design consultants. Where many once relied on advice, there is a trend toward dictating their wants. While there always were some clients who pulled the strings, there is a growing number of CADD-using corporations making the decisions.

There are shifting influences in the construction industry, and the corporation client is moving into the dominant influence position. To assure the effectiveness of their facilities management programs, these clients are now letting contracts to those design firms who can supply computerized data compatible with theirs. This means that the design firm must have the same computer and software as each of the clients who demands it, or access to the same. And the corporate clients do not go for the small PC drawing systems.

It Will Get Worse Before It Will Get Better

As more and more clients adopt their own CADD systems, the CADD decisions made by design firms will depend on who they want to have as clients. Some firms are already into two or three CADD systems to serve two or three different clients. Little needs to be said about how the proliferation of computerized facilities management in the corporate world will compound the problems of design firms. While designers have always formed temporary convenience partnerships to get contracts, clients' computerization will compound this activity, creating strange bedfellows. And, since most design firms cannot afford to have many CADD systems, there will be a trend toward designers becoming captive suppliers to certain clients, with the ball and chain being the common CADD system. This period of confusion in which the computer will dominate client/designer award decision will grow throughout this decade into the early '90s, but will abate with the new generation of computers and the fewer computer manufacturers that survive the continuing shakeout. Compatibility will be less of a problem, especially with the artificial intelligence systems and the tendency toward more standard data bases. The clients' power will continue to grow, and there will be increasing pressure for even greater productivity gains promised by the system of the 1990s.

The Scenario By the Year 2000

Computers will perform the overall functions of a design office in an integrated manner. No longer will individual manual tasks be replicated; the new generation of computers will form the core of the overall practice, and will be used on all projects, from the initial planning right through construction and the continuing space planning changes, remodeling, extensions, and maintenance.

Designers will use the systems to solve problems, gather information, test designs, and to accumulate knowledge from project to project. The designers' instructions will be accumulated in the computer and arranged into rational, organized instructions. When the design is done, the computer will generate the sets of drawings, specifications, construction documents, schedules, estimates, RFQ's, project control documents, etc., with little or no professional interaction. Ultimately, paper output might not be needed.

The Implications

are that many manual functions in a design office will be replaced. Professional functions in a design office are categorized by: (1) design; which is the creative, decision-making part of a project; and (2) production, which is responsible for producing the manifestations of the design in the form of construction drawings and documents. In the design phase, the computer will be an invaluable aid to the professional, but in the production phase, the computer will function almost alone.

Almost eight out of ten architects will be affected by this. Unlike other professions, almost 80 percent of the architectural professional effort in a design office is devoted to the production of drawing and documents and other rote activities. This figure is derived from the way a 'typical' design office functions on a project. Typically, design expense amounts to about 20 percent of the total, while the drawings account for about 50 percent of the project cost. Drawing production, then, is about 2-1/2 times the cost of design. But draftspersons get paid considerably less than designers. According to a recent New York AIA study of architectural salaries at six professional levels, the average compensation of the high levels is often more than 50 percent higher than the average lower-level architect. This means that for production drawings to cost 2-1/2 times design, about 3.8 architectural draftspersons are used for each designer. When spec writing and other document efforts are considered, the ratio of production to design becomes four to one. About four out of five architects are threatened with dislocation from their profession in fifteen years — by the year 2000.

In the engineering profession the problem is similar, but the engineers themselves will be affected less. The engineering draftspersons, who are generally not professionals, will be seriously dislocated, but the engineers, only partly so, due to the growing number crunching and analytical capabilities of the next generation of computers. The growing independent action of the computer as it accumulates repeatable and broadening analysis capabilities will continually reduce the need of certain engineers performing those functions today.

The Solid Modeling Craft Will Be Automated

In many instances, the 3-D color graphics of the next generation of computers will reduce the need for solid models, particularly as holography continues to develop. When solid models are needed, the computer driving a laser sculpturing device will create the model.

Spec writers, cost estimators, and interior designers will be affected in similar ways. The need for specification and cost specialists will be reduced to the caretaking, updating, and quality control functions. Interior designers, who function similarly to architects (and often are) will be affected similarly to the architects.

There Will Be Fewer Independent Consultants

Aside from the computer competitive pressures causing this, the convenience and productivity of computer design will cause more clients to do more of their own work in-house. Many of the larger clients who presently have their own design staffs, and use outside services for overflow work will have less overflow. And those that do not presently have their own staffs will find it more convenient to establish their own staffs.

Building product manufacturers, who presently rely on the independent designers to have their products specified will adopt computer practices to compete with independent architects and engineers. In a few engineering trades, this has always been done; the next generation of computers will provide new avenues for more of these efforts.

There Will Be Greater Specialization

Because contract awards will in part be based on computer compatibility and computer knowledge buildup, there will be a greater tendency for specializing in certain types of industries, private vs. public, and agency vs. agency, in addition to types of construction.

Preparing For The Dislocation

There are the optimistic in the design industry that have predicted that those professionals, particularly the architectural draftspersons, who are displaced from their non-design jobs, will merely become designers. Doug Stoker and Nick Weingarten of SOM pointed out the financial fallaciousness of that logic with some cold hard logic in the December 1983 issue of *Architectural Record*. The client simply will not pay for overstaffed design, and the firm will not pay what it cannot bill. The only way for production professionals to be absorbed in design is for the number of design projects to grow. It is unlikely that the construction industry can grow large enough to absorb all of the dislocated — the industry would have to grow 400 percent in about fifteen years. I cannot recall when that has last happened.

Other experts in the field feel the solution will come by itself. They expect other new jobs (now very specific) to be created by computers. While this has been true in some other computer applications where new industries resulted — particularly the computer industry — the same does not necessarily have to happen in construction design. The construction industry can be better equated to the automobile industry as it was impacted by foreign robotics.

This is an issue too serious to be left to chance.

Take It As An Opportunity

Reexamine the role of the construction design profession. There is already a question about whether many firms are really in the design or drawing business. The computer is a two-way street. While on one hand it will displace people, it can also open new avenues for the enterprising. One such avenue is to play a larger role in the growing facilities management business. Bill Mitchell of UCLA has been preaching this for two years. There are probably other potential areas for growth.

This should be made a priority study program by the major institutions in the construction market: AIA; ASCE; ACEC; ASHRAE; CSI; NSPE; et. al., and should include academia. It is entirely conceivable that government grants could be had for this effort. There is plenty of time to prepare.

Today's missed opportunities are tomorrow's problems.

Harry Mileaf is Director of Technology and Product Development, Sweet's Division, at McGraw-Hill Information Systems Company. He is also Chairman of the Coordinating Council for Computers in Construction.

Alton S. Bradford

Our mission is to plan, design and construct shore facilities for the Navy. This amounts to approximately $2 billion in construction a year. We're worldwide with six Engineering Field Division offices to accomplish our design and construction. We also have nine Public Works Centers that handle our operation and maintenance projects. . ee Figure 1)

The basic building process is a time-phased, fragmented, ad hoc industry. Separate organizations plan, design, construct, own, etc. In the product acquisition process, we bring people together to do the design on a one-time basis and then competitively bid the construction (with a separate group). One would never do that with an automobile or aircraft. We design in-house, but about 90 percent is done on contract with architecture and engineering firms.

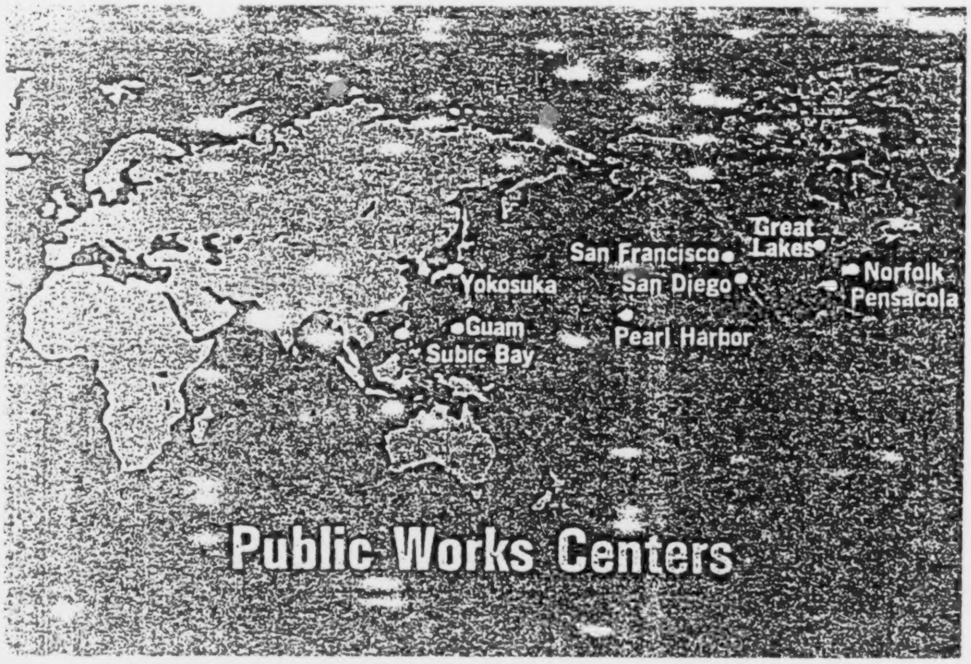
The building process presents many problems and opportunities when we examine it for computer applications. (See Figure 2) In-house, we are doing computer-aided design (design calculation) using time-sharing and personal computers. This includes structural analysis, energy analysis of buildings and such. The work is being done by the engineer at his desk, or the nearby computer computer terminal.

We also do guide specifications, as Harry Mileaf mentioned, using a word-processing system. Guide specifications are documents used to produce a contract (project) specification. The guide specifications and the specific project specifications are both now being done on a word-processing system.

We utilize computers to do project cost estimates. Material quantities are the input and the construction estimate, the output. The factors for labor and material costs, location, economic conditions, projected date of bid, etc., are programmed in. The estimates and actual bids are stored in the system for developing and checking future budget estimates at the programming stage.

Our Graphics Design System, a major advancement in using computers, is well underway. We're installing a computer-based system that uses the language of the architect, engineer and building process people, i.e., three-dimen-

Figure 1



sional (3-D) models. Having always used renderings and models, architects and engineers can now construct and view a 3-D model data base. This model facilitates working with other individuals to define requirements and expectations. We are also able to do two and three-dimensional drawings directly from the data base. Automated production of drawings, specifications, and cost estimates, from the data base, is in the future.

The four basic phases of the building process are quite distinct: (1) plan and budget (market); (2) design; (3) construct; and (4) own, operate, and maintain the building throughout its life. (See Figure 3)

We targeted our computer graphics to that critical decision period (three months) when the parameters and decisions for the building/facility are set. We then use the computer as changes in the design occur. We'd like very much to eventually, say within the next ten to fifteen years, get to the point where we can change the design model and automatically produce the drawings, specifications, and cost estimates.

It's taken us about two years to get computer graphics into our organization. We have installations in our six Engineering Field Divisions and four of our nine Public Works Centers. We are training as many people as possible in the new technology.

The hardware consists of a desk, keyboard, digital pen, and menu of instructions which allows the architect/engineer to sit and do his design work or interact with others involved in the design. (See Figure 4) Individuals, using a computer model, can develop the expectations for a particular project right on the screen. It is simply a work station for the architect or engineer.

We are using some 2-D graphics, but that's only normally communicable between engineers and architects. (See Figure 5) The emerging graphics technology will allow creation of models (three-dimensional) where you don't need a degree in architecture or engineering to understand the project graphics. The technology is increasing as rapidly as the desire to depict objects in the three-dimensional mode. (See Figure 6)

An actual 2-D example is where we take a

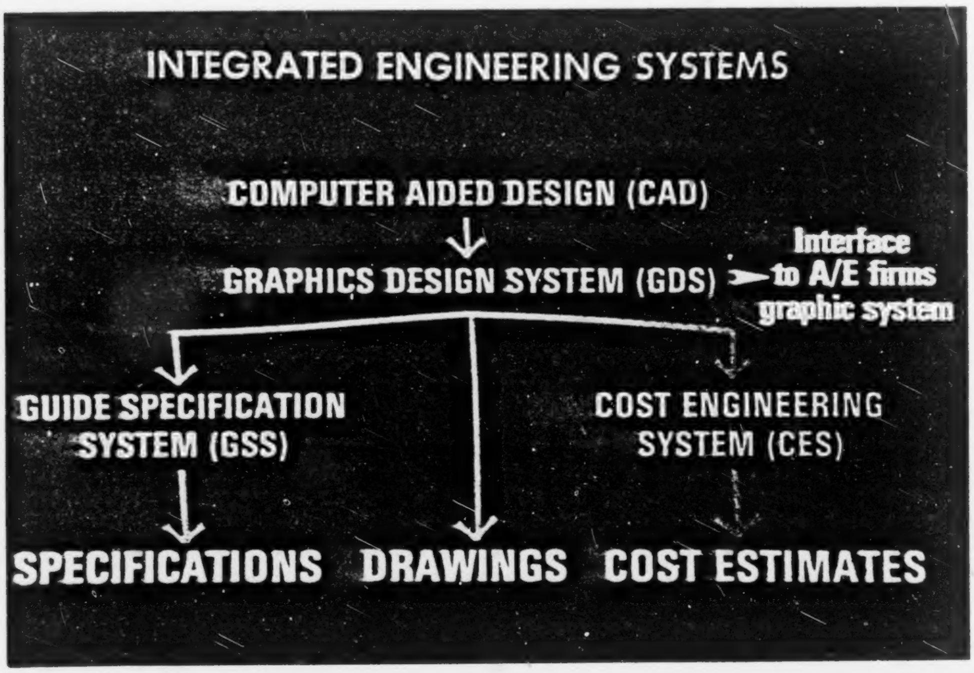


Figure 2

INTEGRATED ENGINEERING SYSTEMS

COMPUTER AIDED DESIGN (CAD)

GRAPHICS DESIGN SYSTEM (GDS)

Interface to A/E firms graphic system

GUIDE SPECIFICATION SYSTEM (GSS)

COST ENGINEERING SYSTEM (CES)

SPECIFICATIONS DRAWINGS COST ESTIMATES

standard room layout and reproduce it until we have a string of rooms. (See Figure 7) We can then mirror image the string about a corridor centerline to produce a floor plan. We add dimensions, notes, etc., and print the drawing. There's no drafting involved. This is an actual drawing that went out to bid. (See Figure 8)

Figure 9 shows a building floor lighting plan. Unfortunately, the black and white print cannot show you the way we use colors. Color is a communication medium, not only between individuals, but between the engineer and the computer system. The Bureau of Standards is working on the IGES (Initial Graphics Exchange System), to enable graphic data communication between different computer systems.

In the future, we'll get away from the big desk units. We're going to see much smaller, flat screen, desk top, 3-D units with more capacity and capability. (See Figure 10)

Maybe a plasma-type screen or something new. We expect, within five years, they will be as common as large desk calculators or personal computers are today. In San Francisco last week, we saw computer graphics on PCs. Technology is increasing rapidly, and prices are in the acceptable range of 15 to 25 thousand dollars. This will be the salvation of many small A/E firms.

He Here are some examples of 3-D graphics. Soon (five to ten years) we will be able to represent an object in the machine as a solid. I have a few slides on this subject. This is a 3-D wire frame model, with some shading. (See Figure 11)

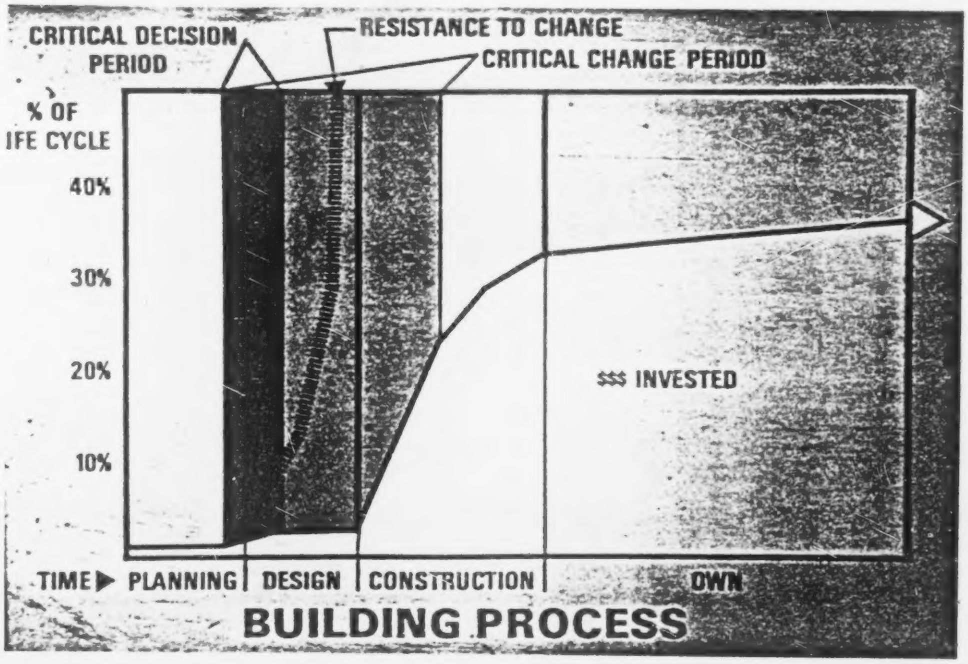
Here is a building with color and shaded surfaces and the lights turned on. (See Figure 12)

And here it is with the lights turned off. We could even pass the sun over the building and get the sun's shading effect. (See Figure 13)

Graphics has always been a communications medium. Now the architect/engineer can communicate with somebody who wants a project, and develop a very clear expectation for the facility or building. One brings a great deal more to, and gets a great deal more out of, a 3-D picture/mode compared to a 2-D floor plan or a list of numbers, letters, or a work description.

We expect widespread use of graphics during the late '80s by the A/E firms (Figure 14.

Figure 3



We're training our personnel and getting involved in the contractual aspects. Graphics data exchange capability between systems will be available. By the late '80s, most of our design documents will require digital graphics data bases in addition to the normal plan, specs, and cost estimates. We think the major integration in the building process will be in the design phase. It is the easiest to get a handle on and utilize data bases for the specifications, drawings and cost estimates. Later (early '90s) we need to get the whole process together. The external data base is an area that we should focus on. This includes the Sweet's catalog type information, generic building products information, codes, regulations, etc. A project integrated data base which is a model from which one would be able to directly produce a set of design documents (plans, specifications, schedule, and cost estimate) appears feasible by the year 2000.

The chart on Figure 15 gives another representation of the building process. We use multiple firms in the process. It depicts the ad hoc fragmented, and time/work phased building process. Therefore, data base development and standardization will be very difficult. Here one sees the Sweet's catalog type external product data base, the main data base within the organization, a project generic data base, and the project specific data base. We're learning as we start to do some of this with our in-house design work to get involved in this process.

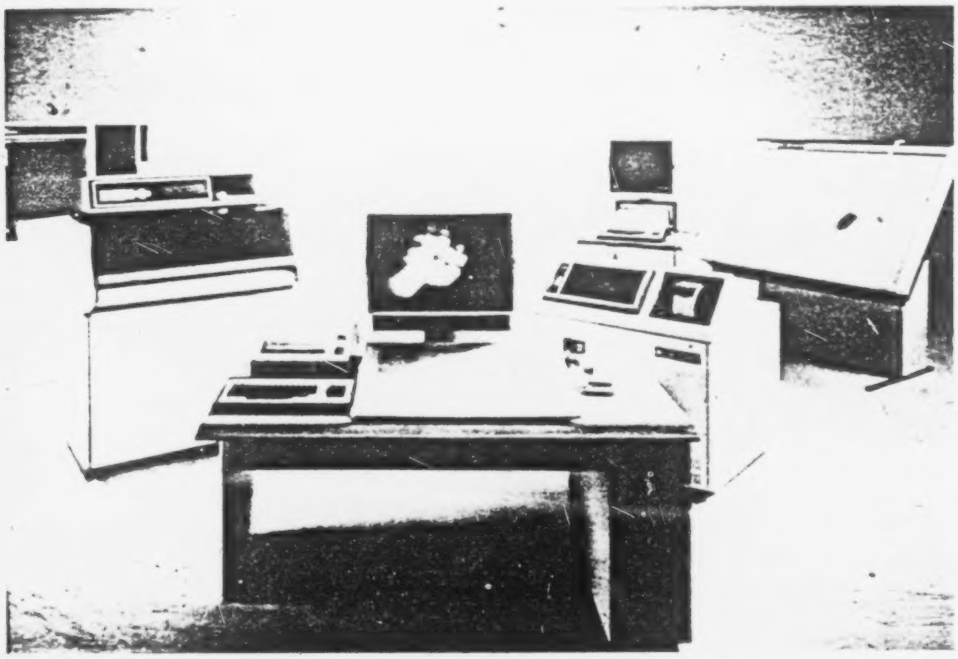
Impacts

These will be my personal views:

The Nature and Form of Buildings

Use of computer graphics will yield more appropriate solutions. The building is a solution to a problem of need. Solutions tend to be unique. We'll be able to give better solutions. We'll be able to integrate building systems for energy and economy. It's not amazing that most buildings are stand-alone systems stuck together in a big box. There will be some standardization. The manufactured building industry is curious about this item. When we design buildings by assembling computer stored, pre-designed building components, standardization will be re-

Figure 4



quired. This will allow faster and better designs. It's going to be a slow evolutionary change.

Quality and Safety of Buildings

These factors are driven by codes and regulations. Computers will be used to check project models against the codes, regulations, standards, etc. There will be an increase in attention to functionality (safety and quality) which will yield better buildings. On the whole, however, I expect no major changes resulting from the introduction of computers.

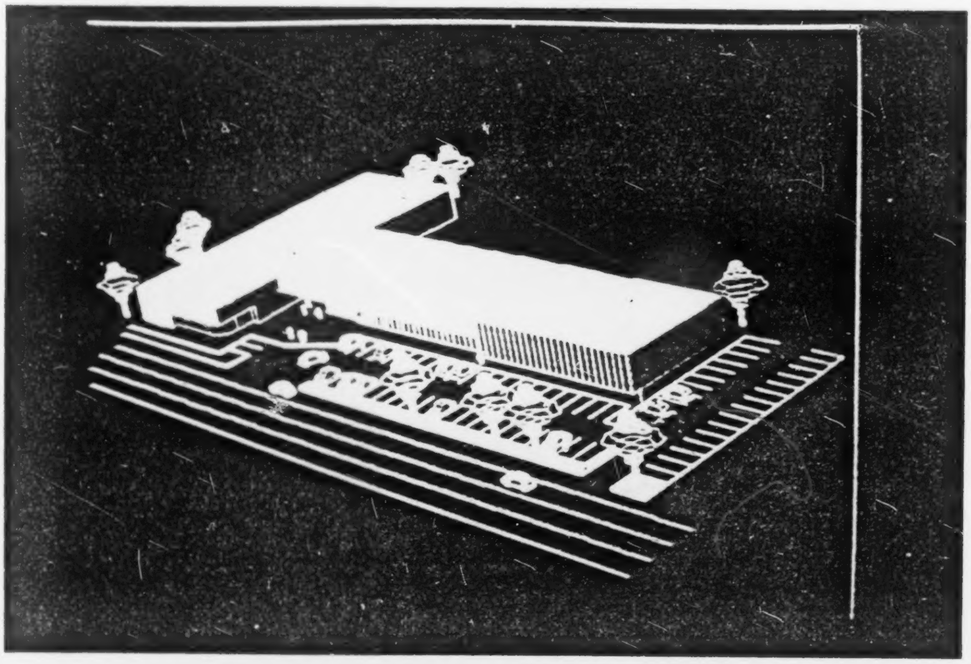
Cost and Affordability of Building

Computers will shorten the building acquisition period. This will reduce the cost and the exposure of the project to change (risk) and, therefore, increase the affordability. We'll be able to better meet expectations. Therefore, the cost and schedules and things of those natures will be firmer, easier to handle, resulting in a noticeable, but moderate change in this area due to computer technology.

Industry Productivity

Computers will decrease the number of changes resulting from misunderstood expectations. Also, with computer technology, we will be able to translate those unforeseen changes quickly into project bid document revisions. This will decrease the time and effort (calendar time and manual effort) required to produce project bid documents, and result in a major increase in productivity. There will also be a decrease in the life-cycle resources. We're going to be putting better buildings together, faster, meeting expectations, and with less changes required during design and construction. The contract documents (drawings) are going to be clearer. They're going to be automated off the system, just like letters coming off a word processor. Drawings will be corrected before they are produced. It's the old bit, that if you produce a good product at the end of the assembly line, you have less returns. We will be studying and analyzing more options, with the objective of reducing, in addition to the initial cost, the life-cycle energy, operation and maintenance, and manning costs.

Figure 5



On Changes in Job Skills, Skill Levels, Occupations

This is the big one. There's going to be a slight net increase in jobs. There is great diversity in types of work in the building process. There's going to be a decrease in the jobs associated with engineering calculations and the direct production of contract plans and specifications. Some jobs definitely will change. One doesn't need an architect to set hours and draw a perspective. It can be done with a computer in minutes. I don't know how familiar you are with computer graphics technology, but one can actually walk through a three-dimensional model of a project (structure) after the data base is constructed on the computer. The data base is constructed using simple drafting techniques; by putting lines, circles and squares, or parts and pieces of building systems together. It's rather quick and easy.

A tremendous amount of information can be used beyond the design phase for building operations including management of rental space, and furnishings. To produce the data during the design is not difficult. It's the result of the interior design, structural design, etc. But to operate and maintain a building and you need to know where every person is, their telephone number, what pieces of furniture they're assigned, their floor covering, date of occupancy, etc. When you start managing change, the data developed during the design, planning, and programming phases become very useful. There will be new jobs and skills required in developing and using this type of data. However, there is a major problem in standardization of communications across organizational lines. None of the ad-hoc groups in the building process needs all of the information developed during project acquisition, and there's no single overseer of the process. This creates a big problem area and contributes to the inertia of the building processes. Change will be slow.

The Role of Engineers

Technology will enhance and improve the designer's and consultant's capability to create, view, analyze (technically, functionally, and financially) and change the project model prior to documentation or construction of the project.

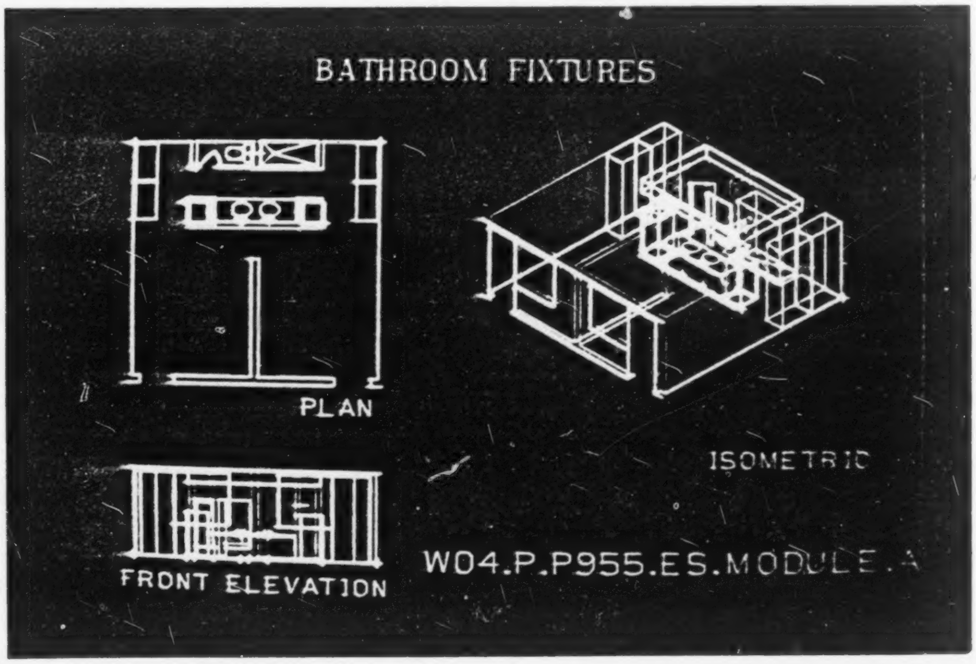


Figure 6

This project information will be retained and updated in machine usable form for latent uses during the construction, operation and maintenance, and use phases of the project life cycle. As a result, the changes in the engineering office environment will be:

(1) A decrease, if not complete elimination, of manual computations. Technical analysis and design will be by computer from building/project geometry data using external code, standards, and product data bases.

(2) An increase in the need for technical expertise that can use computers at a high level of building systems selection and integration. These experienced technical personnel will need to bring good interpersonal skills to the future team approach to effective problem solving.

(3) A sharp decrease in the amount of labor intensive drafting, coordination, and checking as a result of automated drafting systems. Construction documents will be a relatively fast, automated process. Present technicians and draftspersons will be utilized to create and maintain the computer graphics system and data base.

(4) A change in the role of the engineer from 'a designer of buildings' to 'a designer of computer-based systems and procedures' to be used by experienced designers and skilled technical people (paratechnical) to design buildings.

(5) An increase in the use of computer resident, mapping and building process data bases.

In the future the professional engineering firms will be called on:

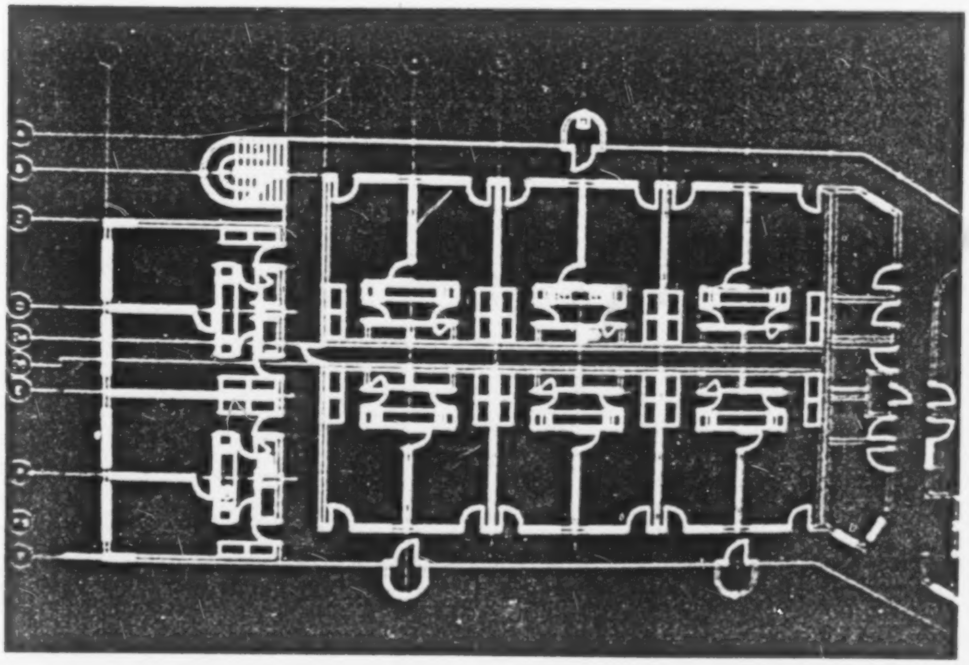
(1) To establish, maintain, and operate computer-resident, mapping and building data bases for the public and private sectors, and operate these throughout the life cycle of the buildings and facilities.

(2) To develop a clear, accurate, complete and timely project definition package (marketing package/budgeting package).

(3) To provide the service of developing the project definition package into a set of accurate and complete construction documents in a substantially shorter time than the present.

(4) To provide a management service, using a project data base, throughout the life cycle or

Figure 7



major portion of the life cycle of the project. This could be an independent service or as part of a joint contract arrangement. This would be a design/construct, construction management (CM) effort with some test-operate-maintain role.

(5) To provide a service to the professional standards organizations, large public and private building owners and other firms in the areas of programming, procedures, standards, program certification, project data conversion, etc.

Education

A large percentage of the individuals coming out of school into the building process, architects, engineers, etc., have a good education in their discipline. The problem is we also need architects and engineers to work together in a team to put a building together. We spend a great amount of time and effort training them to work together. They lack intra- and interpersonal skills. When computers are used to accomplish some of the work, they are going to need the skills to shift into a team problem solving environment. Technical education has got to teach team and social skills. The best course I ever had was in construction planning and programming. Working in teams, we developed projects from conception through to final design detail. The building process will need technical people skilled in working as a team player.

Organization, Number and Size of Enterprises

Small A&E firms are going to survive. Service firms are emerging to do computer-aided design and drafting and to translate documents from one computer system to another. The use of computers in the building process is presently vendor-stimulated and user driven. Data base development, a necessity in the future use of computers, is hampered by lack of standardization, and the very nature of the process. However, the process is changing. Education needs to concentrate on the changes facing people, organizations, standards and traditions in the application of computers in the building process. Teaching technology is not the problem.

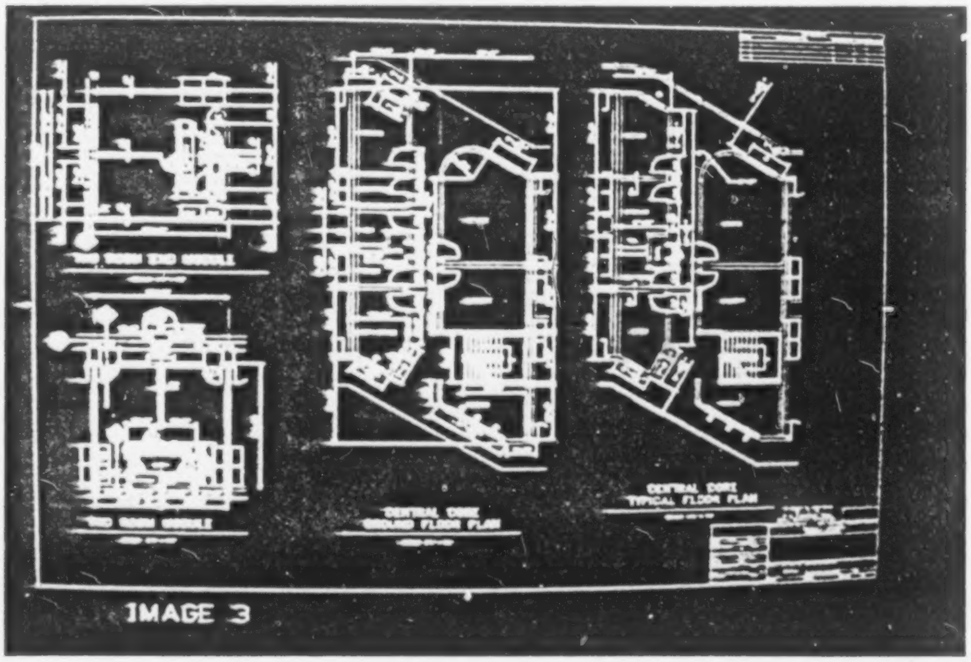


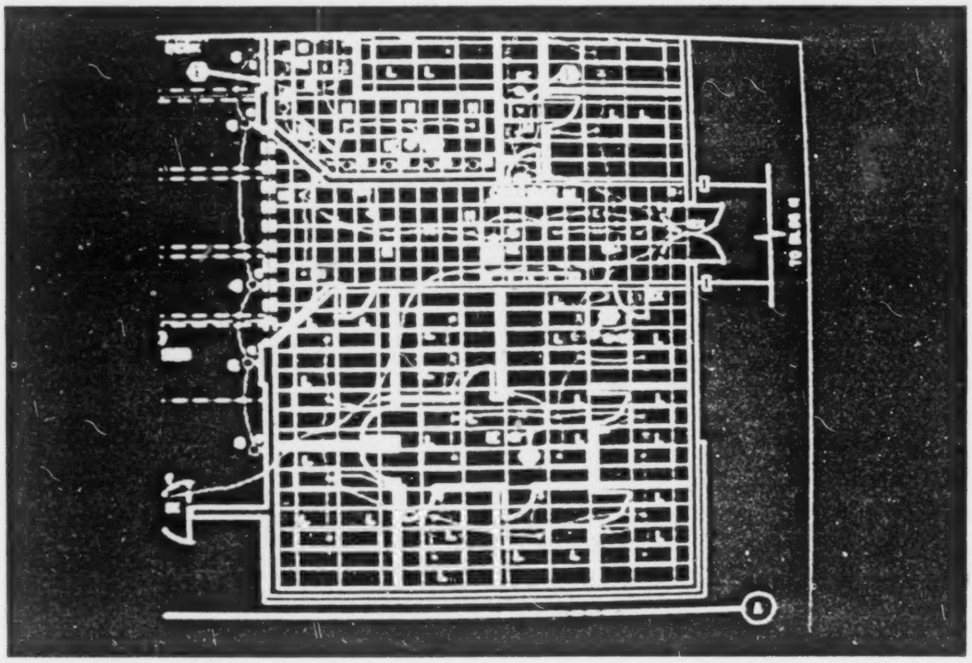
Figure 8

Establishment of structured informational data bases in the building process is one key to the growth of computer utilization. The National Research Council (Building Research Board) is looking at this and other questions on new technological impacts to the building process. Based on some of the study work, there are major changes occurring in the number, size and types of enterprises in the building process.

Conclusion

The federal building process can be described as a sequential, somewhat overlapping, set of easily definable functions. They are: planning, programming, and budgeting; design and engineering; procurement and construction; operation and maintenance; and use. Or more simply, planning, design, construction, and use. Although these basic functions will probably remain the same, the trend in the federal sector is to contract out combinations of these functions. Combining the design and construction functions into a single 'turnkey' or 'two-step' type contract, contracting for the building using a performance specification, and at the extreme end of this construction, staff, maintenance and operation and the user simply pays for the service. Because of major social, environmental, safety, and of course, political concerns, there will also be an increase in the complexity, number and types of predesign (planning) studies required to identify the benefits and disbenefits of the proposed construction. The list of studies will, in addition to the present cost, scope, environmental, energy and schedule studies, be expanded to examine the functional, visual, esthetic, economic, social, etc., impacts on the public and organization environment. There will be an increased need for easily understandable project definition and fast, accurate schedules and cost estimates to confirm and track project expectations. There will be an increasing emphasis and therefore need to deal with change throughout the building planning and design functions in order to hold major financial commitments to the latest possible point to assure the lowest possible risk. This emphasis on deal-

Figure 9



ing with change will require early, more accurate, rapid communications of expectations of the building configuration, function, and cost. Likewise, there will be a need to expend less time and personnel resources on those buildings that don't undergo drastic changes, or are of a less risky nature. This will result in an increase in standardization of building designs (or modular designs), more reuse of acceptable designs, and a major emphasis on having the accurate design data available in an analytically usable form. There will be an emphasis on having ready access to and using the latest, most cost-effective materials, equipment, procedures, and building systems, in lieu of waiting for these to show up in federal standards, design guides or specifications. In summary, there will be a need to proceed from idea to construction start in the shortest period of time with the least risk of financial loss.

Computer Technology

Computer technology, presently available to the building process, is changing more rapidly than our ability to use it productively. Predictable trends over the next 10 to 20 years are that the amount of storage available for computer programs and data will be unlimited or very cost effective. The cost of better and more functional computer hardware will continue to drop at a steady rate while software capability will increase at an exponential rate. The cost of specialized software together with the availability of trained personnel will continue to be the major factors in system utilization. The computer terminal's physical size will continue to diminish while storage capacity, speed and ease of use will continue to increase. Probably the most significant advancements in the next two decades will be the further development of computer graphics modeling, hardware and software, for use in both the visual and analytical interface mode. New software technologies that will evolve include: a neutral, machine-to-machine language; expert programs for building system design; automated drawings, specifications, schedule and cost estimates directly from computer graphic model; micro and macro project products and building systems data

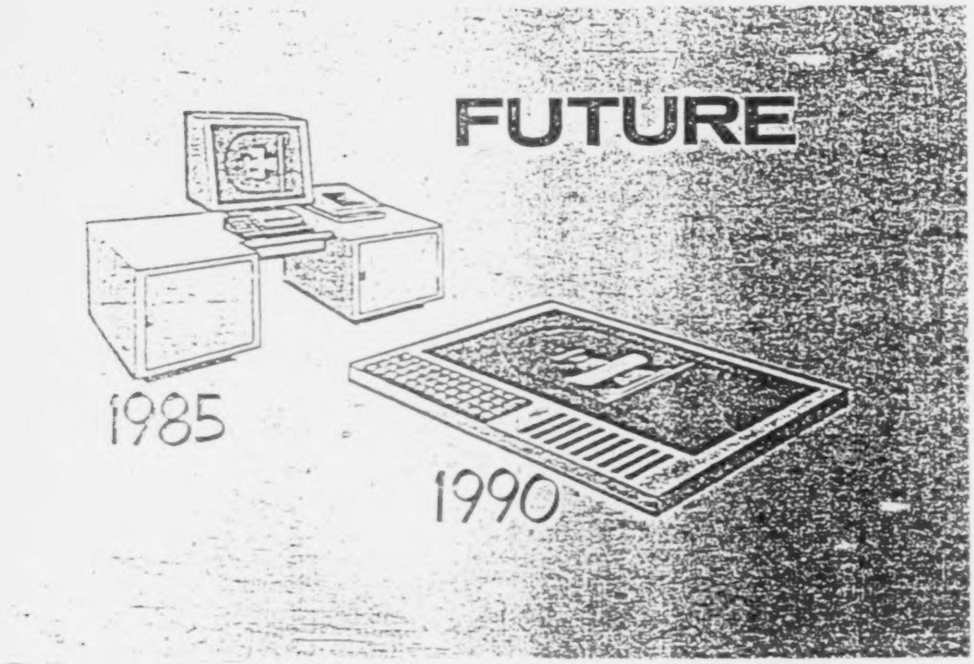


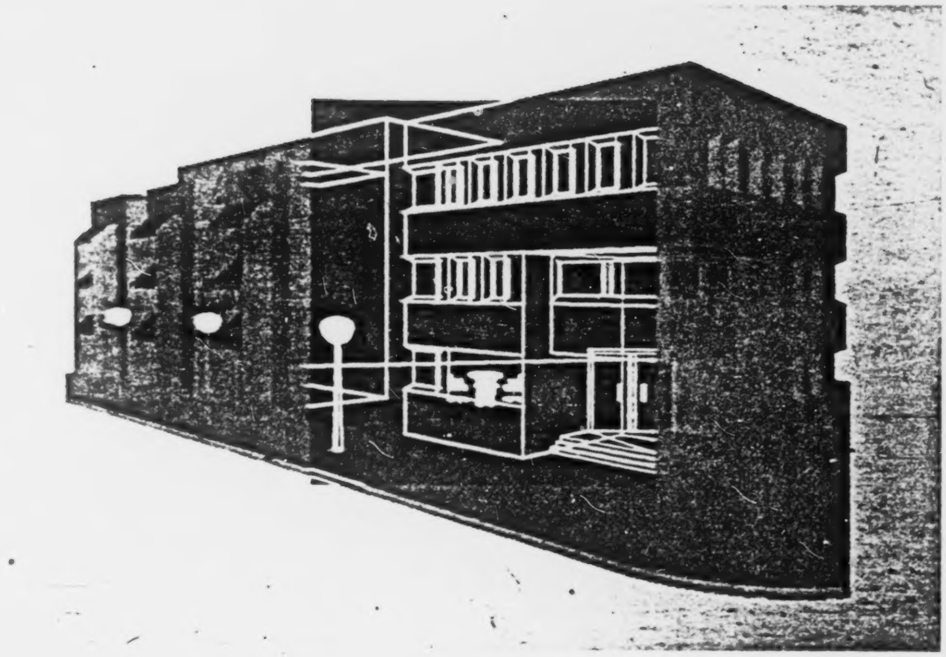
Figure 10

bases; and computer graphics solid modeling. Hardware advancements will include: flat screens; laser readers, printers and storage devices; highly-specialized, plug-in ROM chips and even holographic screens or units.

In summary, the changes in the building process and the concurrent changes in the product and services provided by the engineering profession, will be as a result of needs of the building owner/user. Of course, there will be some iterative interplay between the capability of the professional firms and the perceived needs of, or benefits to, the owner/operator. The major advance in the use of computer technology in the building process will be the engineer's ability to communicate real expectations with the owner, and to communicate with the computer, both using the language of graphics. This use of the technology will enable the professional to provide the owner/user with the much needed project information on which to base critical planning and financial decisions while also being able to react to change without major project delays.

Alton S. Bradford is Assistant Commander for Engineering and Design, at the Naval Facilities Engineering Command of the United States Department of the Navy

Figure 11



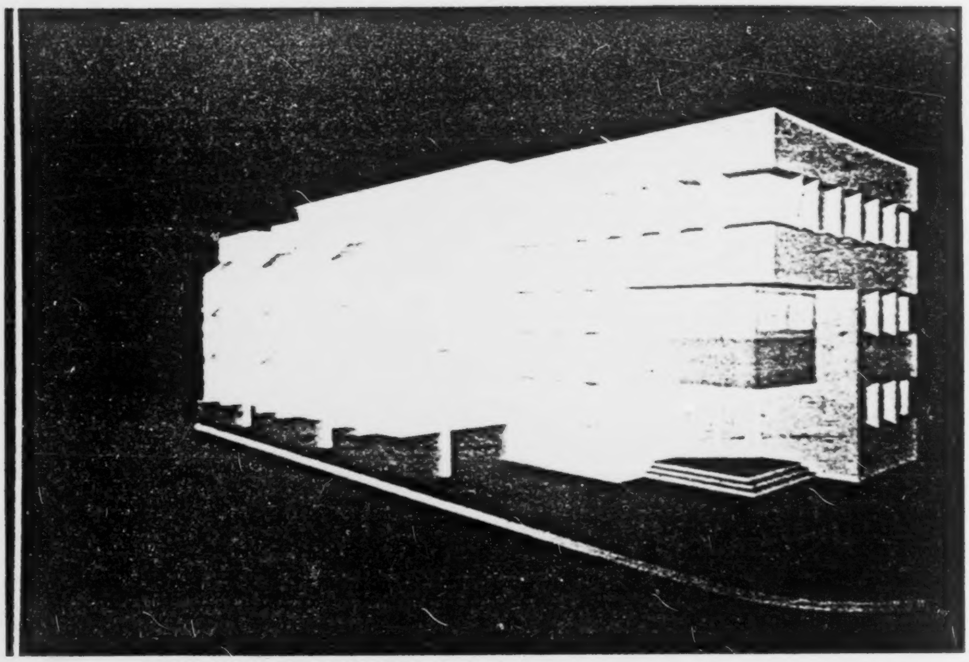


Figure 12

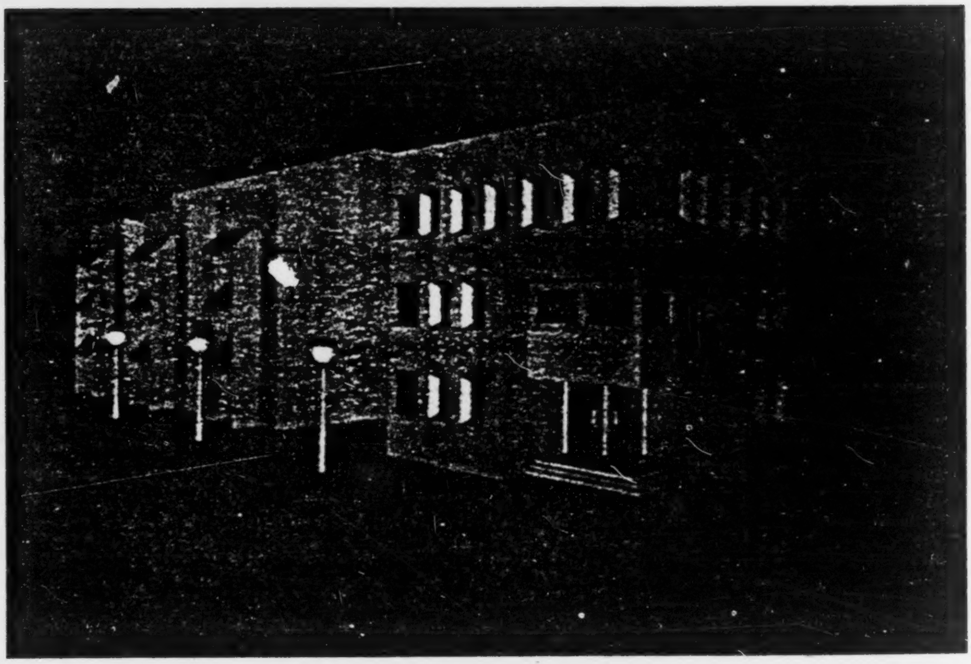


Figure 13

Figure 14

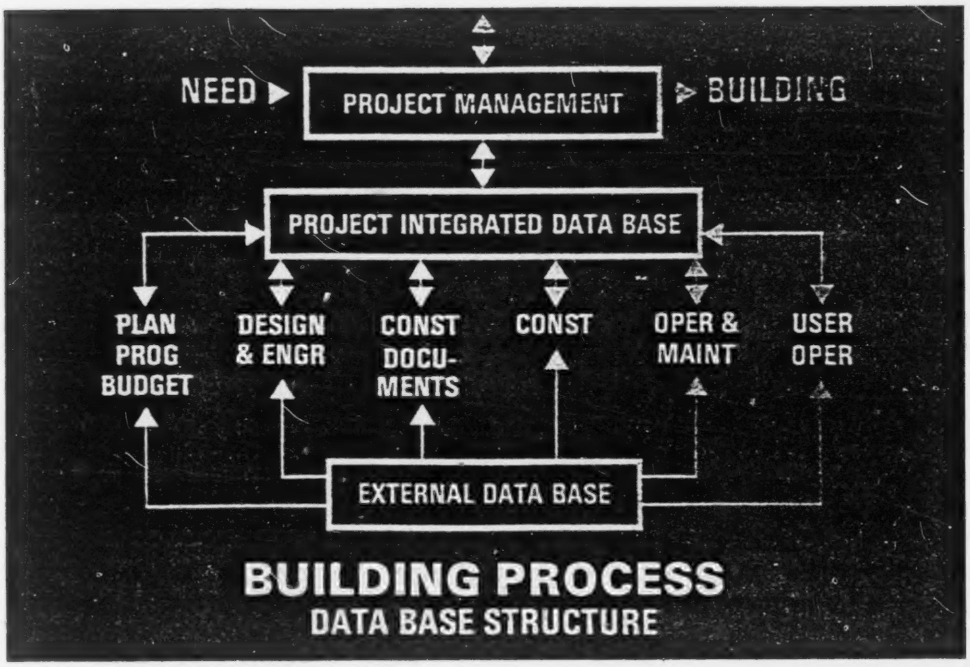
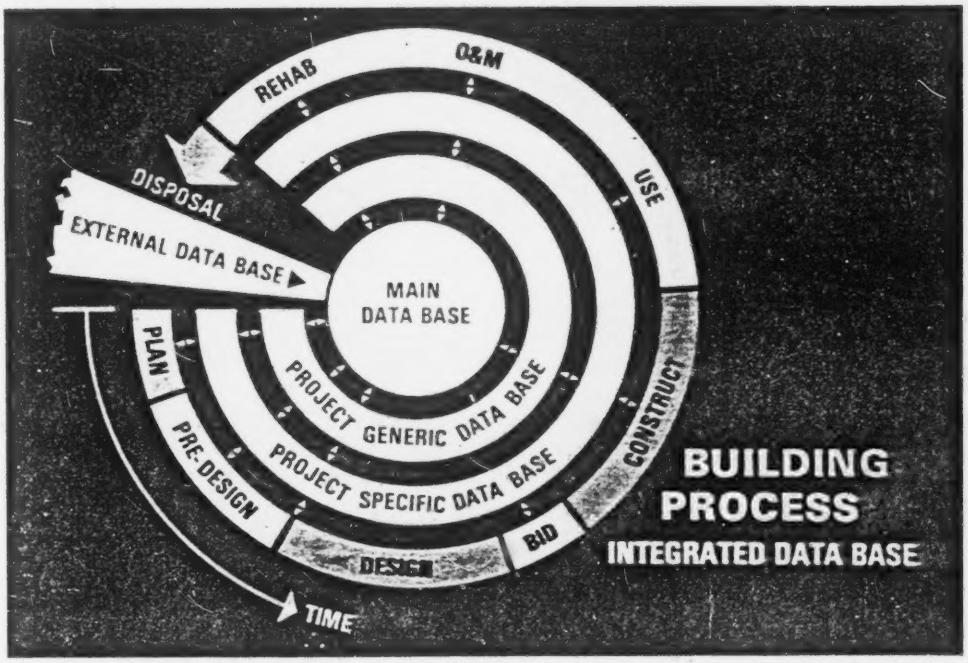

NEED
PROJECT MANAGEMENT
BUILDING
PROJECT INTEGRATED DATA BASE
PLAN PROG BUDGET
DESIGN & ENGR
CONST DOCU-MENTS
CONST
OPER & MAINT
USER OPER
EXTERNAL DATA BASE
BUILDING PROCESS
DATA BASE STRUCTURE

Figure 15


REHAB
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MAIN DATA BASE
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PROJECT GENERIC DATA BASE
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CONSTRUCT
PRE-DESIGN
DESIGN
BID
TIME
BUILDING PROCESS
INTEGRATED DATA BASE

3

Smart Office Buildings

Richard Carl Reisman
Michael Clevenger
Piero Patri

Richard Carl Reisman

Our topic today is the intelligent office building, which could be the most tangible area for automation in the world of offices. I am very delighted to be here with Mike Clevenger and Piero Patri. My part is to tell you exactly what is happening today, where we are now and provide some background, and then set the stage for Michael to tell you what is happening tomorrow, and for Piero to tell you what is happening the day after tomorrow. They will discuss the near and not so near future in office automation, as well as environmental design and office furnishings and systems, and how the related emerging changes will impact us all.

Today we will apply a quote which I am about to read, which has become very commonplace for automation, but we would like to apply that more to 'smart' buildings of today. It is from the local Silicon Valley newspaper, and it says, "Entering its modern form barely forty years ago, the computer already has permeated almost every aspect of American life. Yet no one even remotely familiar with the computer revolution can sanely claim that the revolution is beyond its formulative stages. In other words, you ain't seen nothing yet."

Well, let us apply that to buildings today. In order to do that and explain the impact of automation on construction, I would like to set the stage and talk about some major events that have happened.

Number one, in particular, is the telephone company divestiture. Since they have split up and since they are not doing certain things that they used to do for us, we are having to do them ourselves, and we are looking to private industry to fill that gap. That has a phenomenal impact, and it is hard to get used to.

Most people, and indeed office building tenants, are born with the expectation of the God-given right to have a dial tone all of their lives. When they do not have it, they do not know what to do. Who do they go to? What are the problems? The problems and impact have a rippling effect.

But the void has created some tremendous new business opportunities as well. Not only has the gap created a void that everyone can rush into to provide such services, but we have had a parallel event. While the phone company was busy breaking up, we have had a tremendous advancement in virtually all kinds of computer applications.

Therefore, we not only have a growth of opportunity in that the role of the phone is changing, but new technologies are creating unprecedented business opportunities as well. The combination of these events has triggered an explosive growth in automation.

The impact on the construction industry is that the building sponsor must wire up services in buildings. The imbedded base of wiring and equipment required to provide all services must now be installed as a regular part of the building design.

So much for events. There are a lot of *players* running around, trying to get used to all of this. The *building developers* are the entities, if you will, that build the largest quantity of speculative office space. They are the ones who will face the responsibilities, or perhaps embrace the opportunities would be a better way to say it, of making sure that such services are provided. If they want to stay around and be competitive, they will have to do it. They can determine their own involvement. They can be totally in the office automation business, they can do it part way, or they can arrange for someone else to do it in their building.

There are *corporations* who are tenants or own their own buildings; i.e., some of them lease, some of them develop their own spaces. They are, as a rule, large enough to obtain their own equipment on a non-shared basis, for example, purchase word processors or other equipment which might otherwise be shared by smaller companies. They purchase large equipment themselves, so they are getting into the office automation 'act' as well.

The *realtors*, so far, have been very far behind. They are not up to speed on what is happening in shared tenant services. They are not up to speed in leasing office buildings as buildings which provide services as well as providing shelter. They will need to catch up and may play an important role.

The service providers are in the lead because so much of the office-automation revolution is vendor driven. They are, however, creating a lot of hype, and we are trying to sort out what is legitimate, leading, front-edge development and activity from hype. We are doing our best to serve our clients by sorting all of that out.

Vendors are in the same situation, but they are also grabbing the new business opportunities. IBM has always made office equipment and is now jumping in. They are making furniture. There is a tremendous impact on business, wonderful opportunities, and everybody is grabbing at it.

Honeywell is a little different story. They have always made building controls. Now, they are getting into shared tenant services. So, everybody from the large companies to the small are revising profiles, in light of automation changes and opportunities.

So, given all of these players, all of this background, and the increase in automation, we have need, then, for them to come together in the 'intelligent' building, and an 'intelligent' building is one then that combines two essential ingredients to make it intelligent. By the way, we are in the process of calling them 'intelligent' now, replacing the older term 'smart.' If I lapse into 'smart,' please excuse me. The two ingredients are provisions for computerized (intelligent) building systems, and shared tenant services.

Of the shared tenant services, certainly the telephone services now are the biggest. They are the most lucrative, and of the telephone services, long-distance resale revenues are the most lucrative. Those are by far in the most demand in view of the phone company's split-up, as I mentioned. But, there are other services, as well, such as word processing, data, and a number of other things which we will go into a little later.

The other ingredient that is in the 'smart' building is the building management services or systems. These have been around a little longer. They are the dark horse that have come more to the forefront since the spotlight has now been highlighting office automation. I can walk into a building and take my 'key' (actually a magnetic card) and put it in front of a plate, and all sorts of things will happen, even if it is Sunday night. The lights will turn on the way to the elevator and the elevator will allow me to go to my floor, and the lights will go on from the elevator to my office, and my office will not only function with lights, air conditioning and shared tenant services, but a security system printout will let my landlord know exactly who was in the building, where and when. That is getting to be a pretty intelligent building system.

Everybody is getting into this now and scrambling into the act at different speeds. The Urban Land Institute, which is probably the premium organization of the real estate development businesses in the country, brought the subject into focus in Chicago in June in the conference 'Developing the High-Tech Commercial Project.' We participated in that conference, and the conclusion of the conference was that everybody is still problem solving, and we are all going to get out there in the next two years and build some more buildings and get back together to compare what we have done.

What we are doing is doctoring up our buildings in certain ways to make them 'smart' or ready to be 'smart.' In our particular firm, we are trying not to let a project out of the door that ignores at least some of the design principles which I will touch on briefly here.

We certainly are seeing a change in the mechanical and electrical components of buildings. New demands in office equipment and office environments require that more intense localized demands be met by more flexible systems. You cannot go into a building that is not ready for it and put in a specialized installation and run an extra grille into the ceiling when the system is not prepared for it.

Automated equipment is growing. Cooling is not only required to keep us comfortable while the computers are generating heat, but more importantly, those computers cannot function if the environment is not properly controlled. So, we are seeing 25 to 50 percent more costs in mechanical systems right now. We are seeing a need for 24-hour performance and flexibility. We are seeing a lot more flexibility and, thus, as a bottom line impact, we are generating higher quality structures.

There is a greater cabling and wiring need in buildings. As I mentioned, we have to do the communications cabling ourselves since the phone company is no longer providing it. We are seeing needs for local area networks. We are seeing needs to accommodate more equipment. Indeed, in a 280,000-square-foot project we recently completed, *everyone* in the building had an automated station, a screen and a keyboard. The cabling requirements were absolutely immense. That project happened to be a retrofit.

We are looking for clean signal distribution and clean grounding. This affects certain technical things that we do in the electrical installation, but we are seeing the impact in that cabling trays or racks are common in buildings. Teflon coated wiring is eliminating the large costs of having to put all of these lines into conduit, but the bottom line is still greater costs.

It may be obvious that we are needing things like increased power provisions in buildings to handle all of the new loads, but there are architectural things as well. We are laying out space for all of the equipment to make these buildings 'smart.' We are putting in greater floor-to-floor heights to accommodate the plenums, the wire management, some of the other things that have to be done in the buildings. These things, again, have a cost impact. If you take a thirty-story building and increase the height of the typical floor by six inches, for example, and your marble skin costs so much for each six inches, you can start to see you are adding a story or two of height on the building, a big impact and a big cost item up front.

Even architectural design is affected by it. We are trying to deal with the aesthetics, as well as the technical problems, such as accommodating the equipment or satellite dishes, if you will. The issue is how they look when set atop buildings. These things, as they impact industry, perhaps may not be great, but we are dealing with those human issues, and I have a counterpoint to the lack of design mentioned earlier that I might get to later in the question and answer period.

We are working structurally, preparing the rooftop for equipment. We are preparing our rooftops to bring signals in from the top, as well as we have always done from the bottom.

Our tenant service requirements are typically generating new products, such as flat wire and carpet tiles. They are becoming more present on the scene and they are developing more and more. Michael will discuss this further.

Our building management systems are becoming more sophisticated. I mentioned an example of security systems, but every system in the building is now being run that way. Elevators, for example, which might be more critical and more important in high-rise buildings, now typically have call monitoring happening sixty times per second. Thus, the controller can reassign elevator cars to respond to calls so much more efficiently that we might reduce, say, a high-rise elevator cab requirement from twenty to eighteen and save square footage per floor. I estimate that a $15,000 computer used in this way in a thirty-story building would probably increase the building's value by $1 million through savings in usable area. That is a big impact.

We are seeing a lot of digital thermostat control that gives absolute, pinpoint environmental control. If you put 68° on your thermostat, then that is what you will get. It will not be 69° or 67°, it will be 68°.

The fire alarm system will do far more than indicate the fire on a lighted panel downstairs. It will tell you what kind of fire is underway; it is going to lock the stair doors getting into that floor and open up the doors on the other floors, and it is going to do a number of things which can help with the fire fighting and save lives.

These things have been around for a while, but they are getting more sophisticated, and as I mentioned, they are coming more into the spotlight.

Impacts and Trends

Business services costs, as well as rental costs, will now greet the tenant who walks in the door of the speculative office building. The tenant is looking for service as well as shelter. We do not feel that as of today these services have given 'smart' buildings the edge for making deals versus buildings that have not had them. Indeed, there are probably under one hundred 'smart' buildings up and running in the country right now.

We do see it in five years as being a deal breaker if the services are *not* provided. One just would not go into a first-class office building that did not offer it. But, it is our view that, while the tenant will be spending more through his/her landlord and/or service provider, he/she will have significantly improved performance and efficiency to offset additional costs.

Office buildings will cost more to build, but will make that money back by improved operating efficiencies and lower running costs. Also, we will make money back because people who build buildings have revenue opportunities to resell services. These sophisticated buildings will require more sophisticated people to take care of them. People need to be technologically trained. This is the shortage that we have right now. We do not have people who can adequately run out and really service computer-oriented systems. That is coming around. That will have to come around.

As an industry standard, a Class A office building will have these higher floor-to-floor heights, more expanded and more capable HVAC systems, roof signal communications and distribution for them through the building.

Integrated telecommunications systems provided in the building will simply be a standard, and also better acoustic design and more energy-con-scious design. Light standards, such as glare reduction, all of these things are coming to be higher, but expected, standards.

Mike Clevenger will show you the substantial proportion of the stock of buildings that will have to be retrofitted, but by far, most of those buildings will be able to be retrofitted successfully. We will not have to junk all of our buildings, but a short history of retrofit automation and many variables make predictions and price estimating quite tricky.

For example, if there is a building that is abandoned and there is no tenant and no ceilings, it's quite easy to go in and wire that building in comparison to one that has ceilings and tenants in, in which case there would be great disruption, off-hours overtime and so on.

How much automation does a tenant use; what are the sizes of floors; how old is the building; what is the type of construction; what is the adequacy of the existing electrical service; what was the building used for before? A number of factors make quite complicated the task of predicting retrofit costs in general.

We are doing a lot of it, and as I mentioned, our most sophisticated automated example of anything we have built in the last five years was a retrofit condition, interestingly, in a new building.

The new buildings, which were not wired by the phone company, are perhaps the most demanding. The old buildings that had the embedded wire base have cable running around the building you could hook into and run signals around. It is the recent buildings that do not have the embedded wiring that you have to be careful of.

The big impact then is that we are going to have the more expensive projects being a sum of the traditional shelter provision and the service unit, all better constructed and more automated. So, it is not only shelter, it is also service, and that is what I want to emphasize here.

So, the basis of change is here for our buildings, and we have seen a lot of it happen. Everybody is trying to get into the act, but we now see this explosive mushroom ahead of us compared to what we have had, and as that takes over and as we really go crazy with office automation revolution, we see a lot more change coming in the future.

I would like to turn it over to Michael Clevenger and Piero Patri to tell you what those are.

Richard Carl Reisman is a Principal with Whisler-Patri, an Architecture, Planning and Interior Design firm in San Francisco.

Michael Clevenger

This paper is a short compendium outlining the key points:

1.) The Office of the Future has arrived and will result in fundamental shifts in the planning, design, construction, and operation of speculative office buildings.

Up to the mid-1970s with the advent of the micro-computer technology, office technology had been confined to developments in telecommunications, centralized data processing, reprographics, and word processing. The impact of these technologies on the work place were significant, but not revolutionary. From an office design and construction standpoint, little change to the building development process has occurred since the Second World War, with the evolution of the high-rise office building. But with the emergence of the micro-computer in the mid-1970s, and the related developments in advanced distributive processing, electronic printing, local area networks, software, microwave and satellite communications, a profound change in the very essence of the conventional office development is now well underway. (Figure 1).

Another driving force that's propelling this change is the break up of AT&T on January 1, 1984. The deregulation of the telecommunications industry has created near chaos within the local Bell company operating areas from the standpoint of building wiring, and equipment servicing. In effect, the building owner is now able to directly capture telecommunications (and related office service offerings) within his captured tenant market. This ability to resell communications services creates substantial profit opportunities and risks for the building industry.

2.) The Key Components of the Office of the Future.

The key communication and office automation technologies that are now converging on the office building include:

- Electronic work stations from the most simple personal computers, to high-performance professional workstations and word processors. (Figure 2).
- These work stations are being integrated into sophisticated digital telecommunication systems or PBX systems, allowing both local area communication within the building as well as communication into national and international networks. In parallel to telecommunication systems, these work stations are also being integrated into high performance base band and broad band local area network systems, allowing both high-speed data and video transmission throughout the building. These networks are gradually being integrated into the telecommunication systems utilizing software that allows one system to interface with the other. (Figure 3).
- Attached to the network are shared electronic services including high-speed electronic printers, file servers, and sophisticated, high-quality document scanning devices for document input. (Figure 4).
- Specialized application technologies are beginning to emerge on a shared basis, including video conferencing facilities, electronic publishing centers, public access such as the Source, and Compuserve, and satellite earth stations that permit building tenants to access directly long-distance communications systems thereby completely 'bypassing' the local telephone operating company system at attractive reduced operating costs.

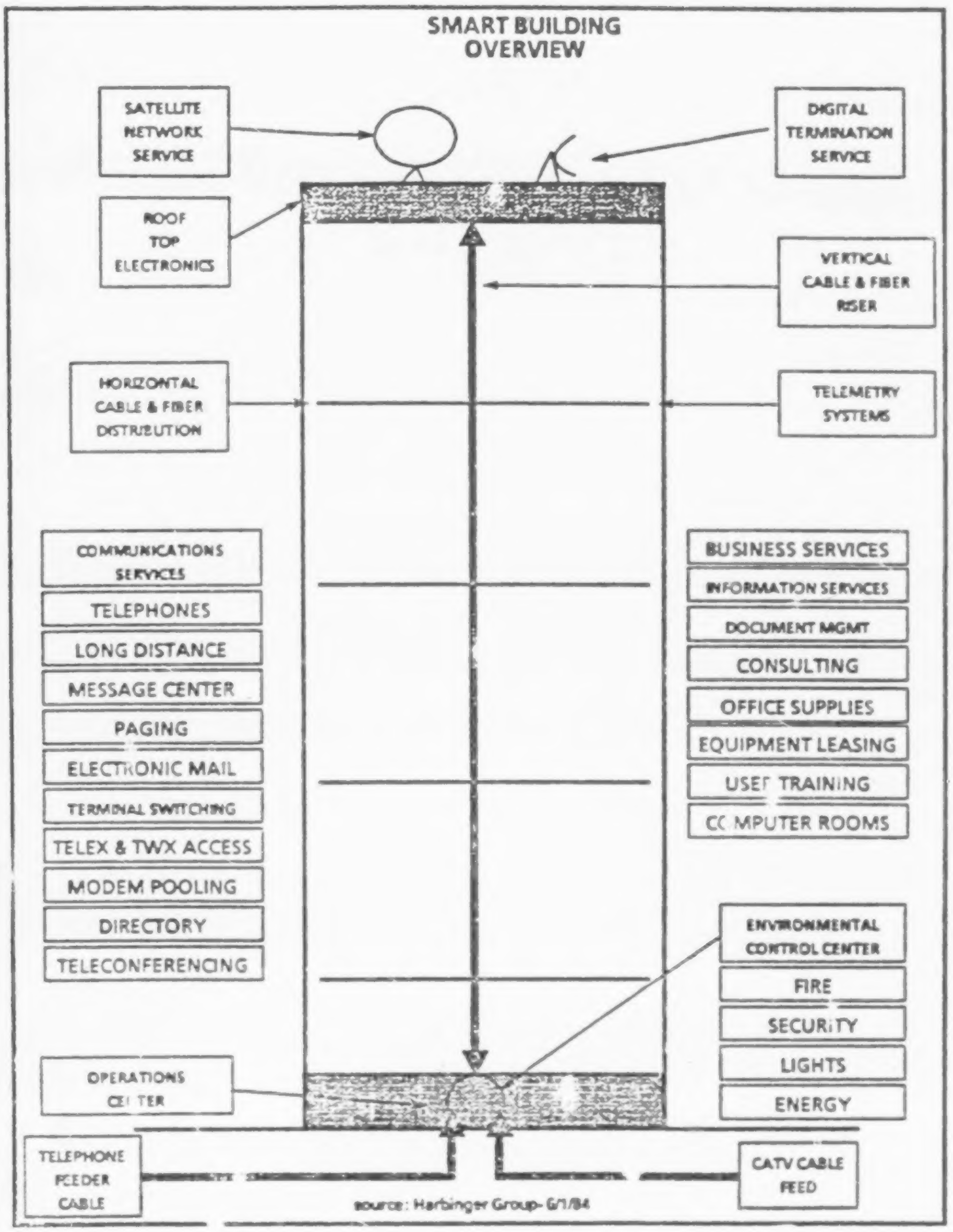
3.) The Growth in Office Automation Over the Next Eight Years, Particularly the Growth of Individual Electronic Workstations or Video Display Units (VDU) Will Create Severe Physical and Operational Problems Within Existing Office Structures Which Have Not Been Explicitly Designed for These New Technologies.

These problems will create significant shifts in demand for commercial office space, both in the location of offices, as well as the configuration and design of offices. Most importantly, this change will also result in a shift in tenant demand for new services as part of the building tenant service offering. (Figure 5).

Some statistics in office automation growth:

- At the end of 1982, there were nearly six million video display units in American industry. By 1990, this number is expected to grow to over forty million units in the U.S. alone, and

Figure 1


SMART BUILDING OVERVIEW
SATELLITE NETWORK SERVICE
DIGITAL TERMINATION SERVICE
ROOF TOP ELECTRONICS
VERTICAL CABLE & FIBER RISER
HORIZONTAL CABLE & FIBER DISTRIBUTION
TELEMETRY SYSTEMS
COMMUNICATIONS SERVICES
TELEPHONES
LONG DISTANCE
MESSAGE CENTER
PAGING
ELECTRONIC MAIL
TERMINAL SWITCHING
TELEX & TWX ACCESS
MODEM POOLING
DIRECTORY
TELECONFERENCING
BUSINESS SERVICES
INFORMATION SERVICES
DOCUMENT MGMT
CONSULTING
OFFICE SUPPLIES
EQUIPMENT LEASING
USER TRAINING
COMPUTER ROOMS
ENVIRONMENTAL CONTROL CENTER
FIRE
SECURITY
LIGHTS
ENERGY
OPERATIONS CENTER
TELEPHONE FEEDER CABLE
CATV CABLE FEED

source: Harbinger Group- 6/1/84

Figure 2

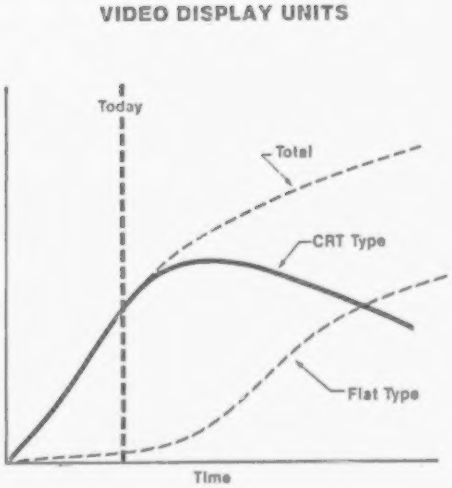
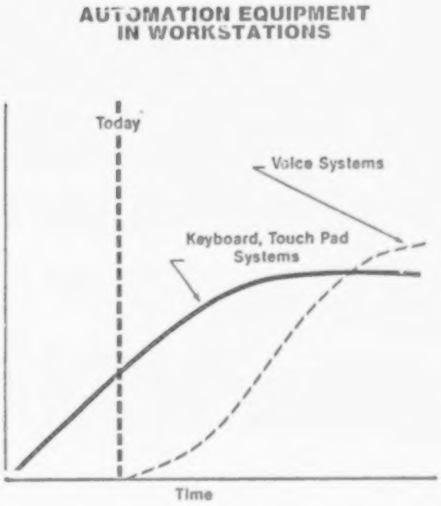


Figure 3



could reach eighty million units world wide by the mid-1990s.

- At Xerox, in 1983, there was roughly one Video Display Unit for every ten employees. By 1986, this ratio will drop to one VDU for every four employees. By 1988, the ratio is expected to be one VDU for every white collar employee throughout the Corporation.
- While there is substantial growth in the number and type of computer terminals, and attendant peripherals, a very small percentage, merely 5 percent of this growth can be accommodated in newly designed and built office structures over the next eight to ten years. The bulk of this technology must be accommodated in existing office stock suggesting that substantial office redesign and reconstruction will be required in the near term. Over the longer term, the miniaturization of product, the advent of fiber-optic technology, and the increasing use of portable (and potentially) wireless electronic workstations will begin to ease the physical pressures on the building envelope. Another mitigating factor will be the growth of the remote or (home worker) employee work force. Recent studies have forecasted that nearly 25 percent of the office work force (primarily professional and clerical) will operate in some form of remote location by 1992. This shift will absorb a fair measure of the demand in the early part of the next decade.

4.) The convergence of these technologies, as well as deregulation of the telecommunications industry, will establish the building owner as a primary information vendor and systems integrator for the second half of the 1980s.

This convergence of the real estate industry with the communications industry will rival, if not exceed, the impact of the interstate highway system on the hotel, motel, shopping center, suburban residential real estate, and recreation industries. The convergence, however, will radically change the building development process and the role of the building owner.

Each of the key participants and stakeholders in the development process will be faced with a fundamentally new set of planning issues to ensure a successful development project.

The key issues relate to:

- Changing technologies
- Building obsolescence
- Changing land values
- Changing regulatory issues associated with deregulation
- Changing real estate markets as telecommunication technologies allow for development in remote areas and greater migration of back office operations from the downtown to suburban centers.
- Changing building operations associated with the management of sophisticated building communication systems and other shared tenant services.

The office tenants will increasingly demand flexible building environments that will readily adapt to changing technologies. Tenants will demand and most likely expect to share in the economies of scale associated with telecommunications resale. Many tenants will require that their office automation systems be compatible with the building systems and networks, and that they can depend on the building operator for service maintenance and equipment replacement and upgrade.

The project lender will require assessments of risk and opportunity associated with the high-tech building. They will be concerned with valuation as it relates to building obsolescence. They will want to assess the effect of these technologies on land values, and what changes in demand and value will most likely occur over time.

The appraiser will now have to update building and land valuation assumptions and methodologies to account for the effects of technology. Assessments of income, cash flow, and discount factors for risk will be required to recognize the fundamental changes in both revenue and expense in the high-tech building.

The real estate broker and builder are now confronted with a new product and new markets for their wares. An office building is now an information utility and communication service center. It is an automation emporium, electronic conference center, and technology service management center. It is a complex envelop of information workers, networks, and technologies

Figure 4

TYPES OF OFFICE BUILDINGS

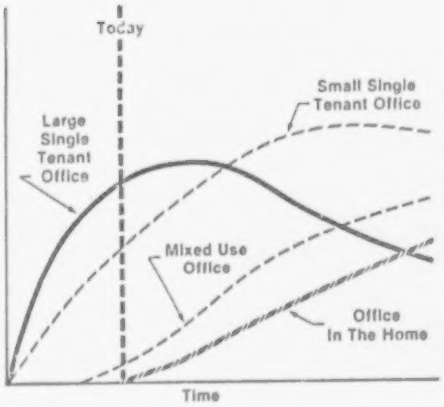
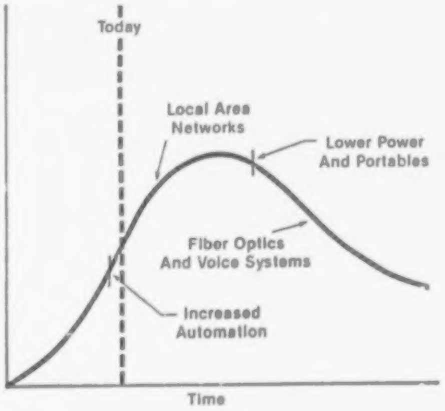


Figure 5

POWER AND WIRING IN WORKSTATIONS



interacting in a highly dynamic mode. It is these products that the broker must now understand in order to market effectively to a newly emerging tenant base.

Finally, the developer/builder who is central to this process must concern himself with all the issues and perspectives of these issues outlined above. The developer/builder must radically change the development planning process to allow for an integrated approach to planning that melds architectural design with systems design, with applications design, into a business plan that addresses tenant markets along communication, automation, and applications segments. Feasibility studies will need to incorporate these new business opportunities requiring new financial assumptions for risk and benefit. New partnerships between the developer, automation vendors, service businesses, and telecommunication companies will need to be assessed. Site selection will have to be evaluated from the standpoint of micro-wave and satellite reception/transmission performance. Regulatory constraints of local public utility commissions relating to bypass and resale strategies will be required. Tenant allowances relating to improvements for office automation will be a key element in the building pro-forma and marketing plan. Studies of competitive activity in the building's market are essential for no other reason than to assess the cost of doing nothing in the new project. Most, if not all of these considerations will apply in varying degrees for the retrofit and upgrade of existing structures. (Figure 6).

5.) Summary

- The office of the future has arrived!
- The building owner/developer/builder will become a key information vendor of the next decade.
- The building investor can expect significant new profitability and risk with this highly dynamic and turbulent new business.
- New partnerships will emerge between building owners and automation/communication vendors.
- Most of the explosive growth in office automation/communications will occur in existing structures.
- The key to success in the high-tech building industry will be a radically updated planning process which integrates the planning for real estate development, telecommunications, office automation, and office services management.
- The payoff for effectively planned projects will be extraordinary.

Michael Clevenger is the Principal Technical Consultant in Real Estate Division of the Xerox Corporation.

Figure 6

PLANNING CHECK LIST FOR THE HIGH TECH BUILDING

Technology Issues

- Telecommunications
- Cabling
- Office Automation
- Integration
- Software
- Services
- Costs

Design Issues

- Location
- Site Configuration
- Building Configuration
- Structural Design
- Floor Configuration
- Vertical/Horizontal Distribution
- Tenant Allowances
- Flexibility
- Antenna Siting
- Building Systems

Financing Issues

- Valuation
- Assessment of Risk
- Feasibility
- Pay-back
- Tax Implications
- Life Cycle Costing
- Allocation of Costs
- Break-even Analysis
- Cost Estimating
- Pricing

Operational Issues

- Vendor Selection
- Technical Support
- Maintenance
- Tenant Support
- Services Organization
- Marketing
- Services Administration
- Contract Administration

Regulatory Issues

- Local Practices
- Public Utility Commission Regulations
- Re-sale Provisions
- Tariff Structures
- FCC Actions
- AT&T Settlement Impacts

Piero Patri

I am going to look at our crystal ball approximately through to the beginning of the 21st Century, basing my predictions on 30 years of experience — not in research — but in the practice of architecture, planning, interior design and, more recently, in facilities management. I am aware of the research that is currently underway at NBS, HUD and elsewhere and am a little awed by the research power in attendance here. I fully expect to learn a lot more today than I will teach anyone.

The subject of 'smart' buildings has been something I have been involved in for a long time. I have here articles that read, *The Electronics Man In His New Office*, and *The Brave New World With Home Electronics*. They are dated December 1972. Pete Valentine, President of Comsul Ltd., communications consultants, and I were interviewed then and talked about the future of 'smart' buildings. It has taken a little longer than we thought for these ideas to come to reality, but the concepts have obviously been around for a long time.

Today I will talk about, one, the future of 'intelligent' or 'smart' building technologies; two, their general impacts; and three, their impact on the future of building construction and related industries.

First, with regard to building technologies, I think all agree that what Richard Reisman and Michael Clevenger talked about earlier is not a 'flash in the pan' or 'pie in the sky.' It is not a question of 'if' but 'when' or 'what form' or 'how,' as Bob Gold said. The cost effectiveness and demonstrated enhancement of productivity from office automation clearly point to their increased future impact on how buildings will be designed to facilitate their application. This, along with reduced costs of building ownership by means of sophisticated building systems, indicates that 'smart' building will be the rule — not the exception — by the turn of the century.

Again, going back in my professional experience, I want to mention two related trends that are merging with 'smart' building technologies, and they are simply the utilization of factory-built components that have been developing for years as a means of reducing construction costs and time, as well as improving quality; and two, flexible building systems to accommodate increasing organizational changes — that 37 percent a year churn that Michael Clevenger talked about — and also the rapidly evolving intelligent building technology.

We do not know precisely what the full impact of office automation and smart building technology will be over the life of a building ten, twenty or fifty years from now. So, as architects, we must build in flexibility or adaptability.

I predict that the 'smart' building itself and the trend toward factory-built components and flexible building systems will merge to create a building that will be qualitatively different from the traditional building we see today.

I would like to take a moment to quote a statement by Joseph Newman of Tishman Realty and Construction Company. "In the new age of buildings, buildings will be better places in which to work, live and interact. Buildings will run more efficiently, be more responsive to the needs of their occupants, and will more effectively accommodate the new high-tech tools of business. More durable, better designed, easier to maintain, and higher-quality materials and products will be utilized. A lot of this is coming out of other areas like NASA and space. In the new age of buildings, more attention will be paid to increased construction productivity and expeditious building cycles. Not only will buildings be more intelligent, providing more effective life safety, security, energy conservation, communications compatibility and environmental control. Those who design, build, manage and own buildings will be smarter."

Well, what does that really mean? As you might expect, these 'smart' buildings will become still smarter, and they will be active, not passive. For example, the building management systems, by means of sensors placed throughout the building, will see, hear, smell, breathe, move, think, prepare and react to changing building conditions. AI, artificial intelligence, is going to be another element that will eventually contribute to buildings interacting with their user. Buildings will not just sit there, passive, as they have in the past. Actually, Arthur Clark's *2001*, I think, will turn out to be a pretty accurate guess. So we had better watch out for HAL.

With the advent of speech recognition technology, voice commands will activate the lights and air conditioning, or command a remote-controlled robotic element of a wall to move. And, most importantly, speech recognition will make the computer accessible to everybody and as universal as the telephone. In other words, one will not need to know how to type or anything about computer programming. This is coming very soon. There are already specialized pieces of equipment on the market that are capable of some level of both voice recognition and synthesis.

Clearly, these 'smart' buildings are going to be more complex, and their elements may not be all of the buzz words we are talking about, but only those that really make sense. They will be modular, standardized, integrated, miniaturized, light-weight, micro-environmentally controlled, and energy efficient.

The next practical step in 'smart' office building design will probably be utilization of raised access floors for wire as well as air distribution, which will provide individualized environmental controls for the user. This, along with glare-reducing reflected ambient light will create a whole new series of design opportunities for the office ceiling.

'Smart' buildings of the future will also be highly *flexible*. That is the key word: easily reconfigured, relocated or replaced. They will take advantage of space technology and will be precision built with the help of computer-assisted design combined with robotic manufacturing.

What we think of traditionally as the building elements — the furnishings and the electronic equipment — will all be wired together to create an integrated continuum with no clear distinction between them. This is the qualitative change we think will take place. Walls will plug into floors. Furniture and equipment will plug into each other and then into walls, floors, and ceilings. Everything will be pre-wired. In my review of the literature in preparing for this presentation, it was interesting to note that a recent study showed that electrical work is one of the areas where there seems the greatest potential for improvement in construction technology.

So the 'smart' building will be an information utility, not just an enclosure of space. The entire building will be like a piece of electronic equipment. For instance, with flat screen technology, walls can become electronic displays either of information or simply color and pattern, creating the possibility of changing the whole character of the office instantaneously.

Signal compression technology that is taking the broad band width of video and reducing it to utilize existing telephone wires will result in every telephone having a video screen so every call will be a video teleconference, if desired.

In the future, other building types will be 'smart,' not just office buildings. For instance, more working, shopping and learning will take place at home with the help of computer and video networks. Donald Sullivan of Arthur D. Little sees the automated house of the future being smaller and containing fewer objects, with robots moving walls and furnishings to accommodate different needs. In other words, the house itself is a robot.

Professor Carolyn Dry of the University of Illinois has studied how the 'intelligent' house can physically adapt to the various needs of the disabled and the elderly, compensating for limited strength and mobility. Japanese researchers are already working on robots to move hospital patients in and out of beds.

Hotels have also started to be 'smart,' tracking when you are in your room and when you have left for improved security, providing fingertip control of the room's environment, and maximizing effective management by providing up-to-the-minute billing information at checkout and alerting the front desk as soon as the room is available for the next lodger.

'Intelligent' buildings will probably be more expensive because of their complexity, even though they will be computer-designed with very efficient use of materials and to minimal tolerances. Shorter construction times and the tendency of electronic equipment to go down in cost will probably help to keep costs in line.

In any case, any greater cost will be more than compensated over the long term of ownership by the added capabilities in building maintenance and user productivity. The demonstrated enhancement of productivity through office and building technology has already increased corporate interest in 'smart' facilities. Now a Facilities Manager can prove to the CEO that spending money to make a building 'smart' clearly has added value to the company's bottom line.

In terms of the general impacts, almost all new buildings in the future will be 'smart' to some degree, and many existing buildings will be retrofitted to be 'smart.' Telecommunications will continue its decentralizing effect. Particularly because it is not only moving back offices out to the suburbs, it is also moving office work into the home. So, I think not only will we have more suburban sprawl, we will probably also witness rural sprawl.

Video teleconferencing will eventually come into its own. Its promise up to now has not been fulfilled, but it clearly is coming and will no doubt reduce business air travel and affect the hotel industry as well.

In general, therefore, regional land use, employment, density and transportation, as well as land values, will be affected. It should be noted that complex telecommunication technology has some centralizing aspects whose impact on land-use distribution has yet to be fully felt. I think in the last decades of the 20th Century, access to telecommunications channels, such as teleports and fiber-optic highways, will be as important to development as access to rivers and bodies of water were in earlier centuries, and access to freeways and airports are now. Availability of sophisticated telecommunications will change the way we use and value land, giving new meaning to the real-estate adage 'location, location, location.'

There is no question in our minds that there will be other significant economic impacts. In describing the buildings of the future, I suggested that there will be an integrated continuum of building elements — walls, ceilings, floors, furnishings and electronic equipment all wired together into an information utility. I have suggested that most of it will be manufactured, pre-wired, and 'assembled' at the site.

This could imply the merging of the construction and furnishing industries with the telecommunication and computer industry. The construction industry, even though fragmented, is the largest industry in the United States, contributing over 200 billion dollars a year to the GNP and employing 10 percent of the U.S. workforce. To quote Marvin Citron of Forecasting International, "Telecommunications has been the fastest-growing industry in the world every year for the last 10 years and will be the largest industry in the world and will have touched and changed the lives of most of the people living when the century ends."

What we may witness is the merging of the largest existing industry in the U.S. with our largest emerging industry. Inevitably, this will have enormous impacts on the way buildings get built, and organization and ownership of the construction industry, and the number and type of jobs in it.

Richard Reisman mentioned earlier that IBM has expanded into the furniture business and Honeywell has diversified its services. Another important example of this merging is represented by Steelcase Furniture Company's acquisition of Donn Architectural Products, manufacturers of totally-integrated wall, floor and ceiling systems. This is a logical expansion for a furniture manufacturer because, in the future, everything will be linked together. Following the pattern of other manufacturing industries, such as automobiles and now computers, I foresee there will be fewer and larger corporations in the construction business, and these companies will be highly automated, more capital intensive, and less labor intensive.

How will this impact construction jobs? There will be fewer traditional construction jobs, as I have already mentioned, with less field work, although there is a bright spot in terms of retrofitting existing buildings to accommodate this new office technology. Even though there's less field work, more work will be done in the factory, but most of that work will be done by robots. So there will be a cap on factory jobs.

Clearly the need for skilled technicians will increase; that is, white- and gray-collar jobs will increase, while blue-collar jobs will diminish. This also applies to the operation and maintenance industries as well. The maintenance worker in overalls with a hammer sticking out of his pocket, walking around in the bowels of a building, will become a technician in a white coat, sitting at a console, checking readouts.

The practice of architecture will change and tend to merge with industrial design and engineering as a result of buildings becoming products of industrial design and a manufacturing process. CAD will increase in sophistication with professional expertise programmed into the computer system as described by Harry Mileaf earlier.

The good news is that some new jobs will also be created. There is clearly a need for more design engineers, architects and industrial engineers, more CAD specialists, 'smart' building retrofitters, laser, electronic, and fiber-optic specialists. We in interior design also see a greater demand for the handiwork of artists and artisans in response to the 'high-tech/high-touch' needs of the electronic office worker.

The bad news is fewer jobs for field construction workers and no increased need for factory workers. Problems will exist for traditional architects and drafters and for blue-collar building operations and maintenance people. Michael Clevenger mentioned the reductions in the users of these 'smart' office buildings from the ranks of the clerical and the middle-management people whose jobs will be automated.

I cannot predict whether the net result of new jobs will balance the old jobs and what effect expanding industries like leisure and health care will have. If we are to believe some predictions that by the year 2000 four million jobs will be taken over by computers, there will clearly be significant changes in employment patterns that will certainly affect the building industry.

Therefore, it seems reasonable to assume that significant retraining and even re-educating will be required for workers within the construction industry, as well as those forced out of other traditional professions I mentioned.

The U.S. construction industry currently seems fragmented and ill-prepared to deal with this upcoming problem. Crucial to success will be a suitably educated and trained workforce and a coordinated research and development effort by the U.S. construction industry to develop and disseminate appropriate technology.

I have already mentioned the problem of the lack of compatibility between equipment and the lack of coordination between regulatory agencies. To be successful in this transition, we must also deal with the problem of the de-skilling and dehumanizing of some of these jobs and the resultant growth in job dissatisfaction among the electronic-office workforce, a workforce that will be better educated, with more job mobility and higher expectations, and a greater willingness to voice dissatisfactions with employers and work conditions, including litigation.

Just to touch a moment on foreign competition, it is clear that the other industrialized nations have a better-educated workforce in the areas of engineering and manufacturing. As an example, the Japanese graduate several times the number of engineers per year that we do. They are world leaders in robotics and appear to be ahead of us in computer-controlled, factory-built housing. Therefore, as more building construction takes place in the factory, they will be extremely competitive.

To summarize, by the 21st Century we are clearly going to be in the Information Technology Age and the Industrial Age will be over. There may be a lot of potential scenarios, but it is clear that this change is going to have profound impacts on the building industry. Specifically, buildings are going to be incredibly 'smart,' complex, active environments and costly.

Secondly, 'smart' buildings are going to be everywhere, and not just 'smart' offices, but 'smart' homes, hotels, hospitals, etc. They will impact land use, density and transportation. In other words, they will impact our whole society and the way in which we function.

Thirdly, we believe we will see the merging to some significant extent of two mammoth industries, construction and telecommunications, with a net loss of jobs and an increased demand for highly-skilled technicians and, with this, the need for re-education and retraining.

Lastly, it is really exciting to be here to address this pressing need in the construction industry. I hope this forum will continue because over the next several years. We must carefully coordinate government policy and private industry goals to fully realize the enormous potential these forces promise.

Some After-Thoughts

There is a pressing need for a better-coordinated research effort in the U.S. Construction Industry. This effort should involve the full range of people in construction: design professionals, building material and furniture manufacturers, contractors, building owners, academics, telecommunications and office automation manufacturers and service providers, as well as government officials. There is also a fundamental need for more in-depth studies on productivity gains attributable to the implementation of office automation and telecommunications systems, especially at the middle management level of organizations.

This research and exchange should serve as the basis for the development of a national policy regarding the future of the Construction Industry, particularly as it relates to the computer and telecommunications industry. It would be my hope that this Committee would serve as an impetus toward accomplishing that goal.

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4

Modular Structures and Related Techniques
Don O. Carlson
Eric Dluhosch

Don O. Carlson

I want to very quickly cover the background of light-frame residential construction. A brief look at history, a look at where we are today, and some looks at where we might go and the possible impacts.

The biggest change that we had in this nation in housing was when a guy by the name of Taylor, a carpenter in Chicago, created what we call balloon framing — the first use of two-by-fours in 1833. This was the major departure from the old European system of heavy timbers and heavy masonry construction.

Strange as it looks, that system really turned the United States into a nation of homeowners. One hundred seven years later in 1940 in Lafayette, Indiana, Jim and George Price came up with factory panelization. About twelve years after that in 1952, this man, A. Carroll Sanford, invented what we call the toothed metal connector plate. This created the component industry, which in a sense allowed site builders to compete with what was going on inside factories by panelizers.

About 1973, the next big breakthrough was the flat-chord floor truss, again, metal-plate connected. Simple as it looks, it enabled us to greatly conserve our natural resources by making it unnecessary to use heavy-dimension lumber in our floor systems.

If you think about America's industrialized housing machine and visualize down the center of that picture a big piece of machinery, there are five manufacturing segments. At the far left, we have what we call the production builder, the big-volume site builder; next, the panelized-home manufacturer. Across from that we have the mobile-home manufacturer, the modular-home manufacturer, and the component manufacturer.

As to who builds what in the U.S. housing pie, these figures are based on our research for 1983. The site builders do about 51 percent; the panelized, 26 percent; the mobile, which we probably should more accurately call the HUD-Code home today, builds 19 percent; modulars about 4 percent. Other segments of this industry include the dealers for the factory-built homes, the component manufacturers who build for the production builders, and of course the special-unit manufacturers, who are all factory builders, but they don't build housing. They build everything else except homes and apartments.

The production builder builds single-family homes, low-rise or garden apartments up to mid-rise apartments. We call him a production builder because he usually builds in metro centers, and one house after another. In the metro center, he is served by the component manufacturer who usually sells these units erected. In other words, when the component truck leaves that house, it's weathered in and the builder can take one month to a year to finish the inside, if he wishes.

Turning to the component manufacturer, this industry was created by Sanford; today there are two thousand of these companies across the country, primarily serving production builders. They are among the most sophisticated machine people because they will serve up to one hundred different builders at one time.

Component manufacturers make wall panels, roof trusses, floor trusses, gable ends, plus other components for homes. They use highly sophisticated machinery. This $52,000 component cutter could be compared to a carpenter with a hand saw over his knee at a job site or even a circular saw. There's not much comparison when it comes to the kind of quality you can get into a factory to the lack of quality in our, as someone said, primitive methods at job sites.

Component manufacturers all make roof trusses. Today this roof truss is engineered for the specific house in the specific area where it's going to be used, for span, wind load, snow load, live load, dead load and so on. It's created with metal connector plates. You see the inverted truss there in the background.

Additionally, the industry is becoming more sophisticated. Here they're using what we call machine-stress rated lumber. This is lumber that's run through a nondestructive testing ma-

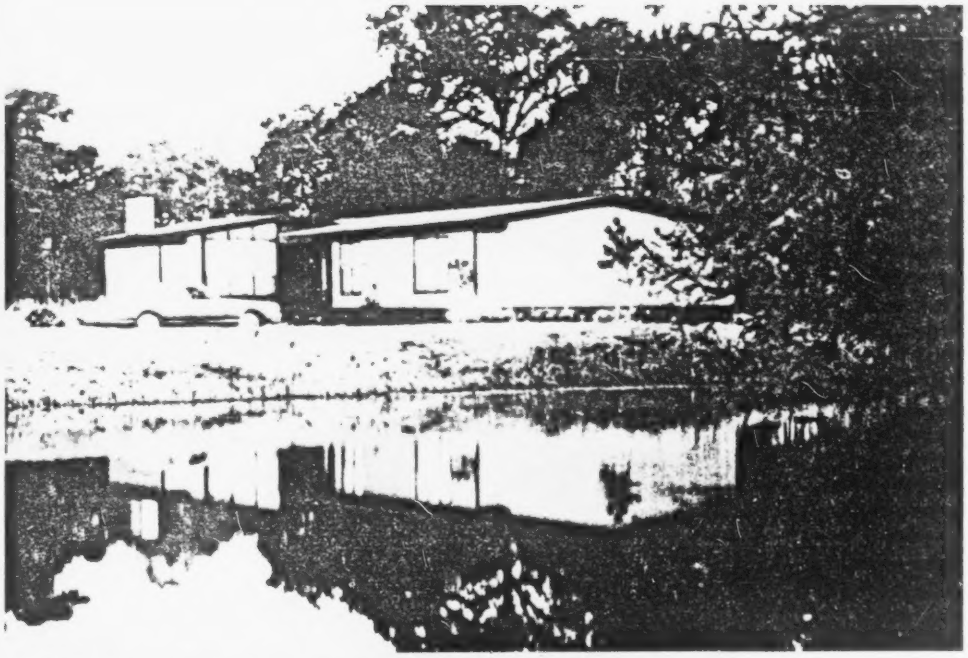


Figure 1

Hud-Code (Mobile) Home.

When built to the Manufactured Housing Construction and Safety Standards Code, administered by the Department of Housing & Urban Development, and placed on a permanent foundation on land which is sold with the home, this variety of housing becomes virtually indistinguishable from any other type of housing, except that the unit will be more affordable, ranging in price from 5 percent to 30 percent less than other styles of housing in the same area.

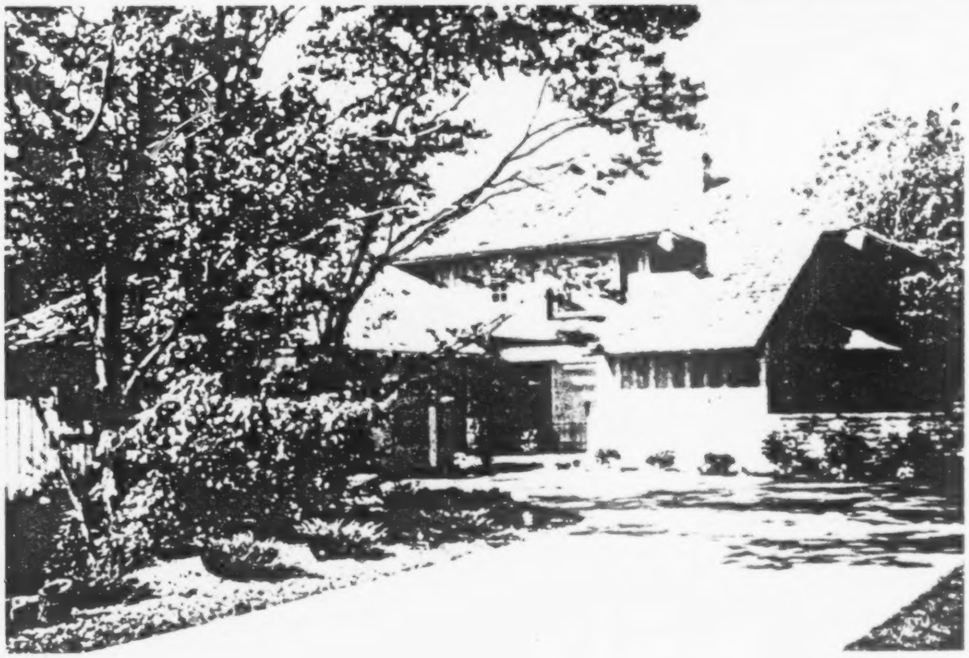


Figure 2

Finished Panelized Home.

Panelized home manufacturers, approximately 600 across the U.S., are the most versatile producers of architectural styles. Their homes can range from low-cost vacation cabins to expensive mansions in excess of 10,000 square feet.

chine to actually find out how much it will bear. This puts this industry's products on a part with steel and concrete.

Component manufacturers also machine doors literally by the thousands. Turning next to the panelized-home manufacturer, there are about six hundred of these companies — of which probably twenty-five are large size. They're very versatile in what they build. They can take an architect's blueprint and create the house that the customer wants. One of the largest plants happens to be in Fort Payne, Alabama, the old Kingsbury Home plant, probably half a million square feet under roof.

Today, the important thing to remember regarding all of these phases of housing that we're discussing is that it is a duplicative process. We're all building the same way. Two-by-four studs, usually sixteen inches on center.

In the panelized plant, if a panel such as this would have sheathing on it, windows inserted, siding on the outside, and then it's delivered to the job site in that condition, even though there's insulation between the studs, we call it 'open-panel,' or 'open-panel panelization.' If that wall panel is finished on the inside and the wiring, plumbing, and so on is put inside that wall, then it becomes closed-panel.

Some of our panelizers use cores, mechanical cores. This little self-contained building will contain one or two bathrooms, the furnace, the hot-water heater, and usually the electrical junction box. That structure goes down on the deck first, and then the interior and exterior partitions and the roof system goes up around it.

Also included in this panelized industry, even though they don't build panels, are the two-by-four pre-cutters; and we do include the log-home manufacturers, of which there's about two hundred and fifty. We also include the dome-home manufacturers in the panelized segment, of which there are around sixty. Now, the dome manufacturers actually panelize using five triangles to create a pentagon.

Turning now to the modular home manufacturers, like the panelizers, the log, and the dome, they build to our model building codes; that is, a conventional building code. There are about two hundred modular manufacturers across the nation. Their technique in construction is very similar to what goes on in a mobile-home plant, except they're building to different codes.

This is a typical kind of jig they use for their roof system.

Here's one of the newer plants which happens to be Summey Corp. down in Georgetown, Texas. Their technique is to fabricate their walls on wall-panel machines at the head end of the line and then tip them up onto the floor systems as they go down the production line; and then in the far background, you see the modular boxes, as we call them, getting ready to be shipped out of the plant.

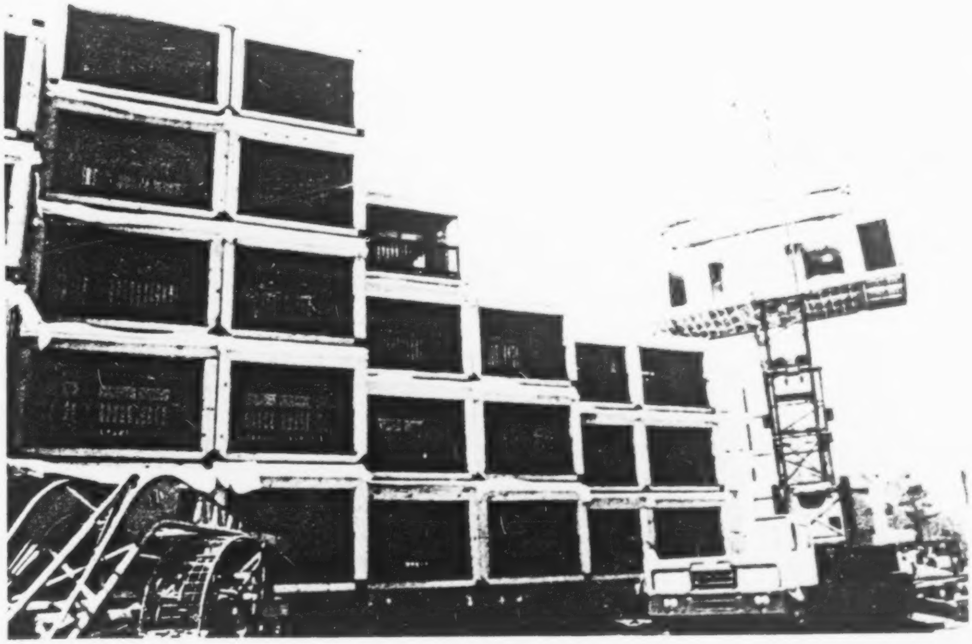
The technique in many plants flows along a production line with fourteen to sixteen stations. The flooring systems are stacked up there at the right. They put down their resilient flooring and their carpeting. They put in their plumbing fixtures, interior partitions, exterior walls and a roof system as the units go down the factory line.

Modulars are about 95 percent complete when they leave the factory if they are going to be a single-family house. We call the modular the strongest of all construction systems used today simply because it's glue-nailed, plywood construction all the way around. Even the marriage wall has plywood glue-nailed onto the wall studs. This makes each half of the house essentially a self-contained box beam, and the modulars are traditional over-builders. If it takes two two-by-fours to do the job, they'll use three.

At the job site, if the terrain is rough, they'll place them with cranes. Now, that wet wall of a modular will weigh up to twenty-six-thousand pounds, and yet, as you can see, it's being totally supported by cables at just two points.

A major trend along the coast, the East Coast of the U.S. and the Gulf Coast, is what we call the stacked modular, up to five or six stories tall. These units are sold primarily now as recreational condominiums. They're very, very attractive.

As in all industrialized construction, which covers all of these units, the biggest saving is in your construction loan interest costs. A project of this magnitude, if it's modular, can be finished in about six months compared to about a



Figures 3 and 4

The Use of Stacked Modular housing units is becoming increasingly popular for apartments, resort condominiums, and motels. The modular units (referred to in the industry as 'boxes') are 95 percent completed inside the factory, then shipped to the job site and stacked by crane up to four and five stories tall. The major advantage for the builder is that in a large apartment complex he cuts his construction time by 50 percent with resultant savings in construction interest loan costs which can run as high as $100,000 per month. In a large project, the use of stacked modulars will cut construction time from more than one year to less than six months with resultant interest cost savings.

year if it's site-built; and a project of this size will probably save up to $100,000 per month on construction loan interest costs.

Finally, the HUD code manufactured home, which we used to call the mobile home. Of course, they've not been mobile for many, many years. This industry has two of the greatest advantages going for it ever visited on any segment of housing: one, it has a national preemptive building code; and two, as of about the middle of last summer, you could finance these units just like conventional real estate, providing they were permanently mounted on foundations on their own lot.

Trends in this industry are to make these units look more and more house-like, to make them more appealing to the consumer/buyer.

Construction technique is the same as we use for anything else, two-by-four studs, sixteen inches on center. In this case, you can see they're getting their shear strength from glue-nail on the interior materials. However, when it comes to insulation, you can order what you want — R-11 or R-19 walls.

One of the departures is lighter frame construction than we use in most other housing. Like in this particular mono-roof system, they're using two-by-threes instead of two-by-fours. Well, the question is: What do you want to buy, a Chevrolet or a Cadillac? These homes are in the Chevrolet class.

Going down the production line, they're similar to the modular production lines: the floor system first; then their plumbing, partitions, wall systems and roof systems put on at the end.

By law, the mobile must have a metal chassis beneath it, and you can identify them if you can get down underneath to see that it has a metal chassis. If you see this, you know that it's a HUD-Code unit.

Manufactured-home dealers — there are around fifteen thousand of these dealers (probably nine thousand handle mobiles), and the rest are into panelized, combination mobile-modular, the log, the dome, and so on.

The special-unit manufacturer, as I mentioned earlier, is a factory builder. He builds things like doctors' offices, prisons, motels, everything except private housing per se.

One of the difficulties in marketing today is to tell the difference between a modular unit, which is what we're looking at here. Those units beneath it are not chassis — they're transporters. They'll go back to the job site after this unit is set at the site.

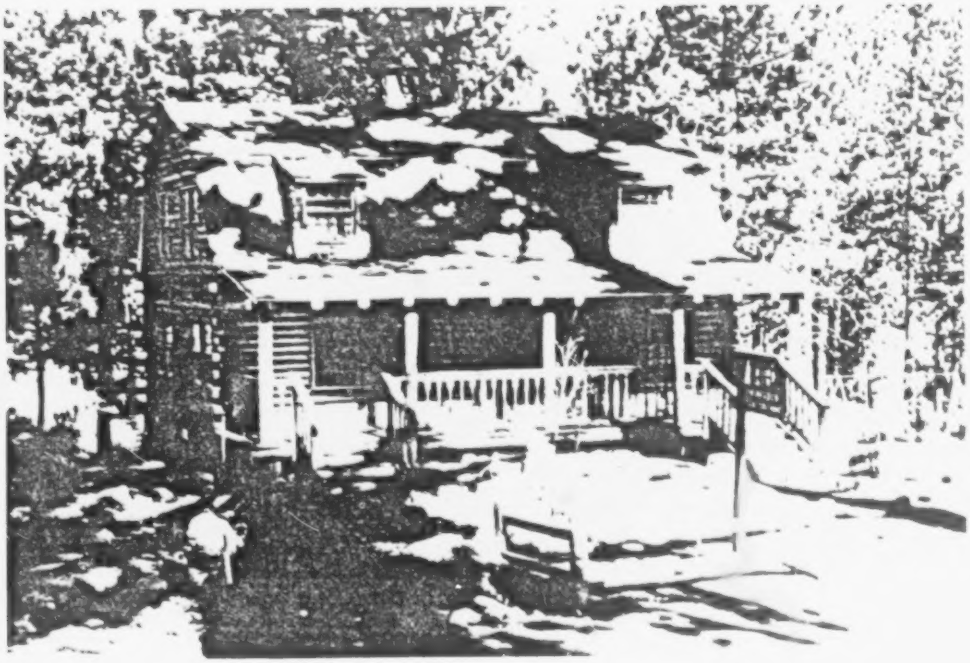
Here's the mobile, or HUD-Code, home. Both mobiles and modulars have house-type siding, roofing, windows, and doors. They've got three and four 12-roof pitches. They look like little houses, but depending on the market you're in, the mobile (HUD-Code) homes are going to run anywhere from 10 to 35 percent less costly than the site-built, comparable unit.

They're striving to make these HUD-Code homes appealing to the consumer. And when these units are placed on permanent foundations, such as this particular project in Rancho Ventura, California, which went on permanent foundations and was sold with the lot, they look good; but the price in that area, even though it might sound high to you, was $71,000 to $91,000. A comparable site-built house started at $130,000. As you might guess, they sold like hotcakes.

The interiors of HUD-Code units are very professionally decorated today. The kitchens use brand-name appliances. If there's a choice, of course, between good, better and best, they probably go for the good because we're talking low-cost housing.

Other Trends in Our Industry: Because of the rise of the component industry, the computer has been used for many, many years (over twenty) because every roof truss we build has to be engineered on a computer. Today we're getting computers into wall panelization. In this case, a girl can look at a builder's blueprint and do the input into this computer. The computer will actually drive this wall-panel machine out in Gardina, California; and that machine will turn out walls for a three-bedroom house in about three-and-a-half hours. However, it's limited. They can't build gable-end walls such as this. So there are many other semi-automated systems of wall panelization. This is just one. It happens to be a wall-panel plant in Chino, California.

The high-speed plotter has already replaced draftsmen to a great degree inside our compo-



Figures 5 and 6

Log Homes and Dome Homes

are considered part of the panelized home group. There are approximately 250 log home manufacturers in the U.S. and Canada, mostly small firms, and about 60 dome home manufacturers. While greatly desired by some consumers, the total number of units of both built each year is less than 150,000.

nent plants. That high-speed plotter is computer driven, and it can do the work of about five draftsmen in about an hour.

One of the minor trends through the South (Louisiana, Texas), is what we call metal-plate-connected rough openings. It's one of the toughest jobs at a job site to get a square opening for your windows and doors, and this component solves that problem for most of the apartments being built down in the Texas area.

Another trend that we expect to see more of because it makes so much sense is the permanent wood foundation, sometimes called the all-weather wood foundation. This is made from pressure-treated lumber and plywood; and as you can see by this scene, you can build it anytime, including in a blizzard. You don't have to worry about what the climate is outside.

The permanent wood foundation creates a basement level that is just as livable as the upstairs. And, depending on where you are and what insulation is being done, this unit will range anywhere from 20 to 50 percent less costly to heat in the basement area. Since this was invented by NAHB and a few other groups back in 1969, we've built about one hundred seventy thousand of these. We expect them to proliferate.

Another trend is that the big builders are getting bigger. These figures show the top one hundred home builders. Now, these top one hundred cut across all lines that I've mentioned. In 1982, they built 304,000 units; in 1983, 377,000 units. The percentage of what they built went down, as it always does, during a period of prosperity in housing simply because more small builders come into the marketplace.

Japan — let me just touch on that briefly. I led a study mission to Japan in April of this year. When I left this country, I was very smug about our superiority in housing technique, marketing, manufacturing, and so on. It took about a day and a half for those ideas to get knocked out of my head. My conclusion today is that they're about eight to ten years ahead of us in marketing techniques and manufacturing technology.

This is how they sell their homes. You're looking at an aerial view of a model city wherein sixty to seventy builders bring their homes into one place. Mr. and Mrs. Japanese Home Buyer can go in there. After they pick out the architectural design and their house style, they can sit down with a salesman at a computer, do the final analysis right on that computer, literally draw the house on the computer. Then they can go in a make selections of all of their wall finishes, what color they want the kitchen cabinets and so on.

If the order is finally approved, the salesman can punch a button on the computer, and the order is electronically transmitted to the factory, and the house starts down the production line.

In terms of code, they have a national code set by the Ministry of Construction. They want their homes to not only be energy efficient, but capable of standing up to earthquakes, their typhoons and so on. Of the ten largest Japanese companies, about four have capabilities of completely testing the total house inside their laboratories.

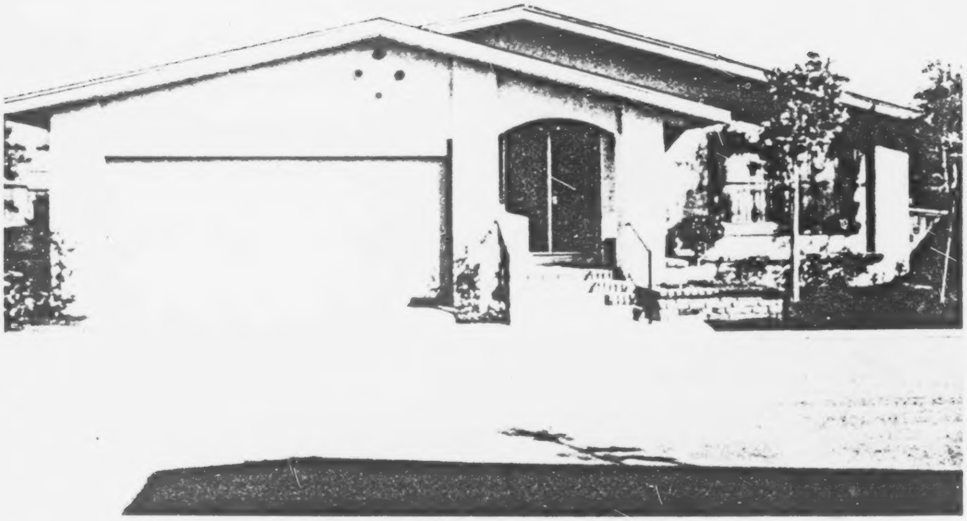
This machine is capable of hitting that full-size house with winds and rains of 140 miles per hour, and those windows don't blow out.

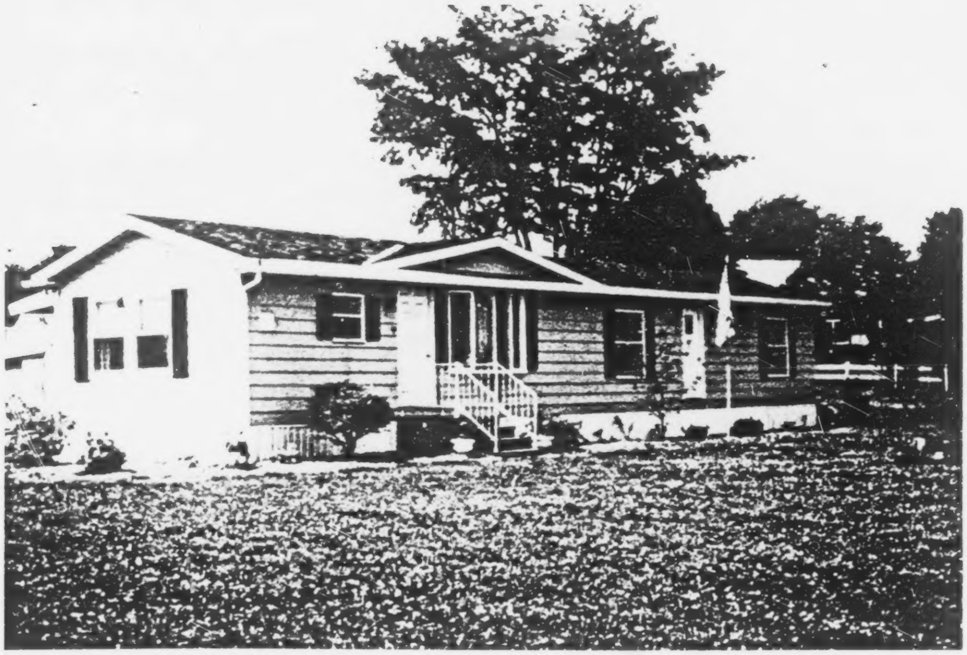
In terms of conveyorization and automation in the factory, they're much further advanced than we are. That happens to be a wood panel, a stressed-skin wood panel plant up in Matsumoto, Japan. That production line went at a steady rate of fourteen feet per minute; it literally never stopped. Every station was controlled by a sidebar computer, which in turn was controlled by a master computer.

They're deeply into robotics for the steel panels they build. This is a robotic unit to create steel trusses. They wouldn't let us photograph the wall-panel system, but it was all robotically welded. The members came down very, very quickly; went into a system where eight robotic welders hit it all at one time and then moved the panel out; and it only took a matter of a few seconds to create a complete steel-wall panel.

The Manager in that plant told me very gleefully, "We're building houses the way we build cars."

This is a new material invented by Misawa Homes. That white panel you see at the end they call precastable autoclaved light weight ceramics, or more simply PALC. The PALC





Figures 7 and 8

The Major Trend among HUD-Code (mobile) homes is to make them look more and more like 'conventional site-built dwellings.' The top photo shows how panelized garages can be placed in front of double-section HUD-Code homes to make them look like typical California tract homes, the lower photo shows that the 'conventional home look' is even being adapted for single-section homes panel in one unit there gives you your exterior finish, your interior finish, your structural support, vapor barrier, and insulation.

In talking with all of these Japanese companies, I naturally asked the question: What are you going to do regarding the U.S.? They all said, "We're not going to do what we did to you in automobiles. However, we would like to form partnerships with major U.S. companies and bring our technology to the U.S."

Misawa claims they will have a factory in this country within three years.

Even by Western standards, what they're building is attractive.

Today we already know how to build affordable houses which are also affordable to operate, even with present levels of technology, without going into a sophisticated $20,000 solar system. This is a building we built in Carpinteria, California, to house our office facilities. It has an all-weather wood foundation, a heat pump, an air-to-air heat exchanger; and, to make a long story short, we run thirty-seven items of electrical equipment, twenty-four lights, and the heating, the air conditioning, the furnace fan and the air-to-air heat exchanger fans, and the whole ball of wax, costs us about $2.50 a day to operate.

The foundation was built in a factory in two days or — pardon me — one day by two men who had never seen a wood-foundation blueprint before. The building was built in a factory in eight days. The foundation went in on the ground in one day, and the building was set in about a half a day.

But then as we always say, building at the site is 'building by surprise.' So after the building was set, it took us eight weeks to move in simply because the environmental people in the area wouldn't let us move in until every single blade of grass was planted, and they picked out the blades they wanted planted.

Possible Changes and Impacts: As I mentioned, Japan is eight to ten years ahead of us in CAD/CAM manufacturing, controls, conveyorization, automation, and robotics. They do want to form U.S. partnerships, and I think, if nothing else, we need some sort of a study to cope with what's going to happen in terms of their future intentions in housing in the U.S.

Other Possible Changes and Impacts: We now have one national preemptive building code. That's the HUD Manufactured Housing Construction and Safety Standards. We have three model codes, which are used by the rest of the nation — the basic, the uniform and the standard. Beyond that, there's anywhere from seven to actually fifteen thousand local or regional jurisdictions that decide on what goes into a house. I think what we need is a national preemptive building code, performance-oriented to certain locations, revised to include known methods of cost-cutting (the NAHB has a library on what we already know about cost-cutting), and the new performance code can be merged to include the three model codes and the one HUD Code.

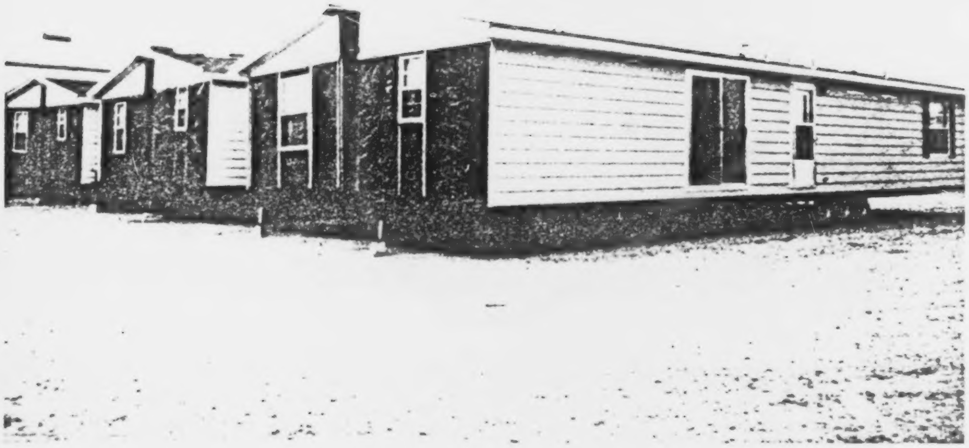
We probably need a similar national preemptive zoning and infrastructure code. Using the known techniques of cutting down costs in subdivisions, this would cover things like streets, sidewalks, sewers and so on; this, I think, would be one of the major methods we could use to reduce costs of housing in the U.S.

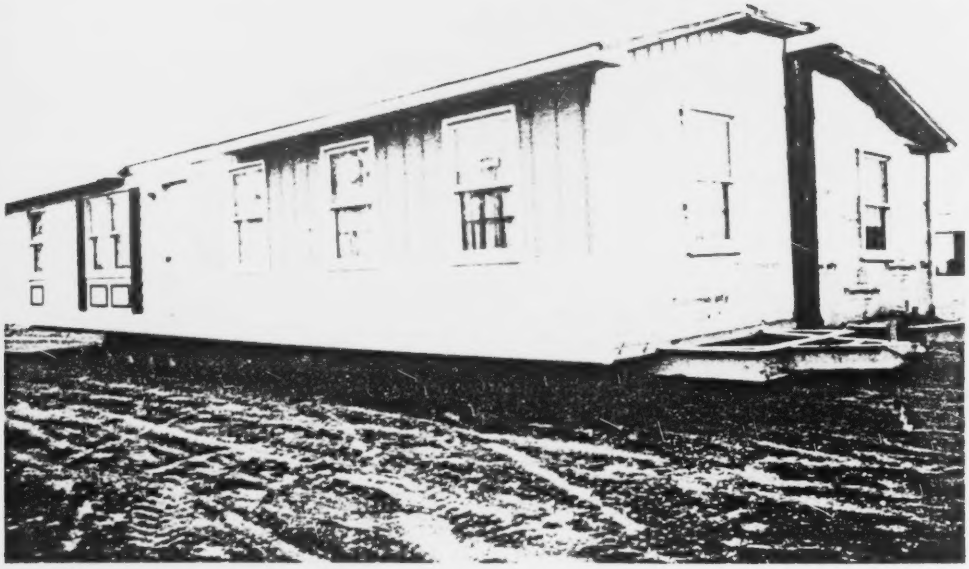
Today we have a Department of Housing and Urban Development. It never seemed to me that was a logical marriage, simply because there's not an awful lot in common between the two. When you're talking about urban development, you're talking probably about rehabilitation. You're talking about heavy construction, old infrastructure. Housing deals with things that will go further out in the country. It may make sense, therefore, to divide the two.

Additionally, we have no less than three Government agencies who get their fingers into the housing pie with inspections, mortgage insurance and so on. Perhaps the time has come to merge the FHA, the VA, and the Farmers Home Administration and their separate codes under the Department of Housing and have a separate Department of Urban Development to concentrate on revitalization, primarily through free-enterprise zone systems.

It seems to me the only way we're going to be able to rebuild our cities is the way we built them in the first place. They were built in the first place literally like free-enterprise zones.

Other Possible Changes and Impacts: The Japanese are well along in working toward util-





Figures 9 and 10

A Major Problem facing the housing industry today is the inability of people both within and outside of the industry to discern the difference visibly between double-section HUD-Code (mobile) homes, shown in the above photo, and double-section modular homes, shown in the lower photo. Mobile homes are built to the HUD-Code, modular homes are built to any one of the three national 'model' builder codes which in turn have been adopted by states and cities. In general the modular homes are built with a much heavier framing system than is used by the mobile-home industry. The major difference is in the fact that, by law, the HUD-Code (mobile) home must have an integral metal chassis beneath each section; the modular section, on the other hand, is simply delivered on a flatbed trailer which is returned to the plant after setting. Nevertheless, since both units are beginning to use conventionally-pitched roofs, house-type siding, windows, and doors, it is visually most difficult to discern differences. The major difference is in cost where the mobile is built to meet the Chevrolet budget, and the modular is more like the Buick or Chrysler budget.

ity self-sufficient homes and apartments. If we tap Mother Earth and Father Sun, I don't think it's too far a conclusion to come to that we can eventually, not too many years down the road, have a home or an apartment complex that's totally self-sufficient of utilities.

I think one of the solutions to our energy problem is right under our feet where, you know, if you go down into the earth, regardless of where you are, even three or four feet, you hit an even temperature, which is always warmer in the winter and cooler in the summer. We're tapping this in the building in Carpinteria, and I think that's one of the reasons that our heating and energy costs have been so low.

Also, we've got to mentally reposition our trees to be renewable and harvestable large-corn stalks, and not just museum pieces. The American forests have to be repositioned in our minds to be enclaves of multiple use rather than just a low-use bank vault for two or three people that hike into the wilderness forests every year.

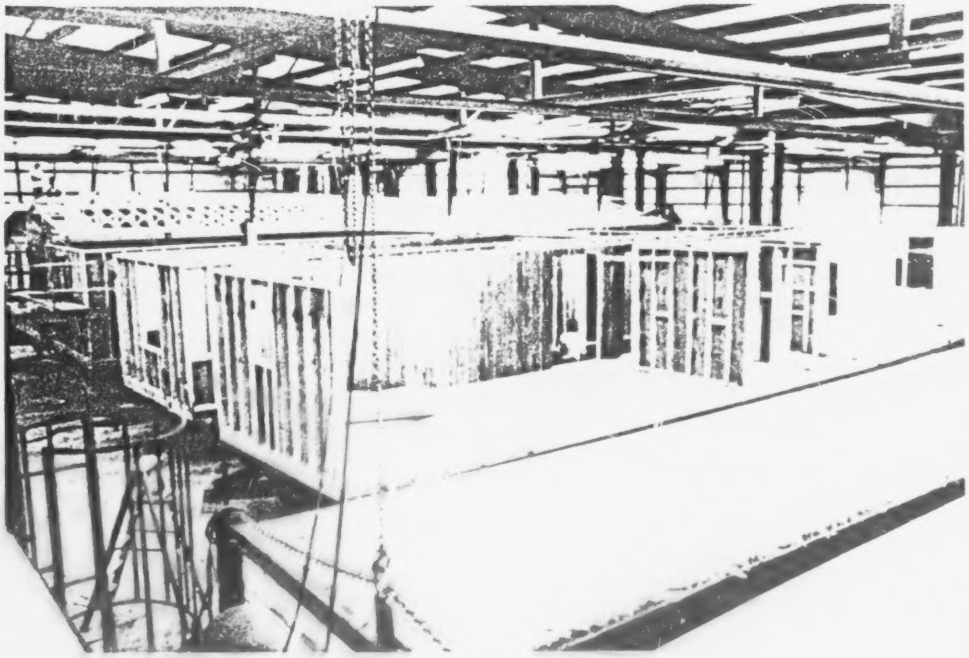
Perhaps we should consider home projects or communities for the homeless. How many homeless are there? You hear figures ranging from three hundred thousand to three million. Who can count the homeless? You can't find them. The point is there are a lot of them out there. Perhaps some of these families should be allowed to involve themselves and build their own experimental low-cost homes; and there's all kinds of experimental systems that we could use, whether adobe, pre-cut logs, dog-bone (profile) lumber, etc. It may be possible to develop systems that we could export to underdeveloped countries.

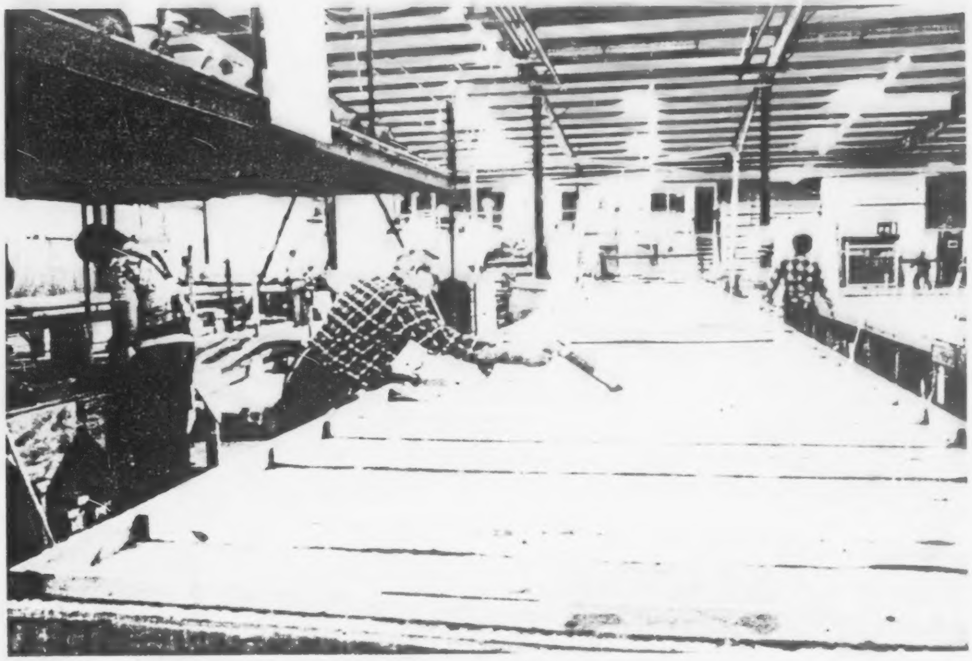
Other Changes and Impacts: I think we need a national 10 percent home mortgage plan. It's axiomatic that when housing is going up, the country's prosperity goes up and vice versa. Why should we continue to crucify the American economy on a destructive down cycle of new home construction?

Our present mortgage interest tax deduction system has been historically insufficient to head off recessions in this nation. If we had this 10 percent plan aimed at the first-time buyer, I think we could achieve a steady rate of two million starts every year. This would bolster 330 groups of separate businesses and industries that depend on housing for a large share of their cash income. Literally tens of thousands of individual companies are involved in these 330 groups.

It would obviously increase employment and certainly increase the Government's tax income at all levels, helping to reduce the deficit, and, I think, finally head off recessions and possible social upheavals that could occur if too many people are homeless.

Don O. Carlson is Editor & Publisher of Automation in Housing and Manufactured Home Dealer Magazine



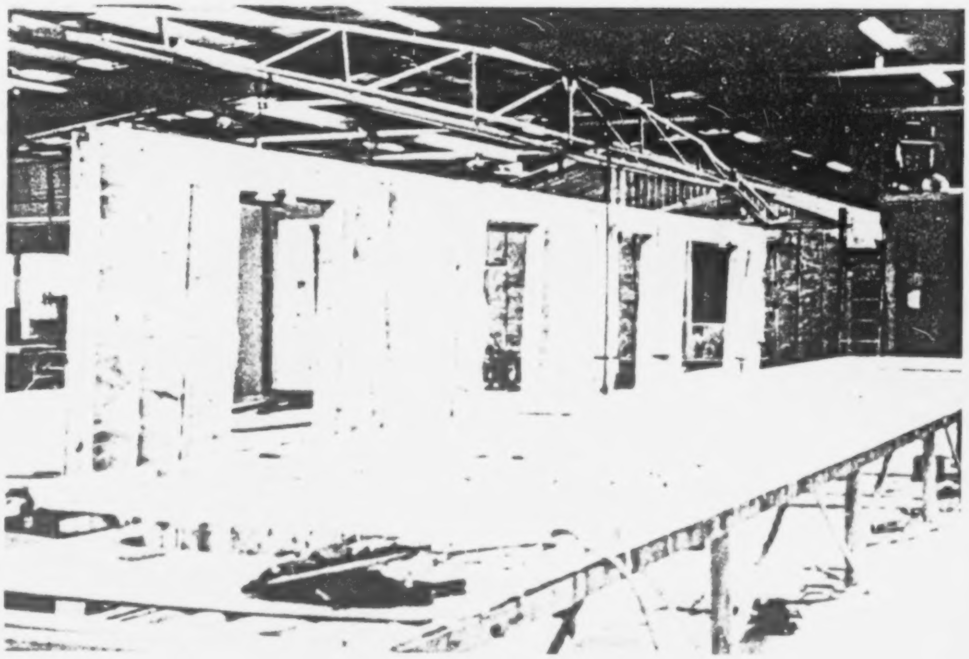


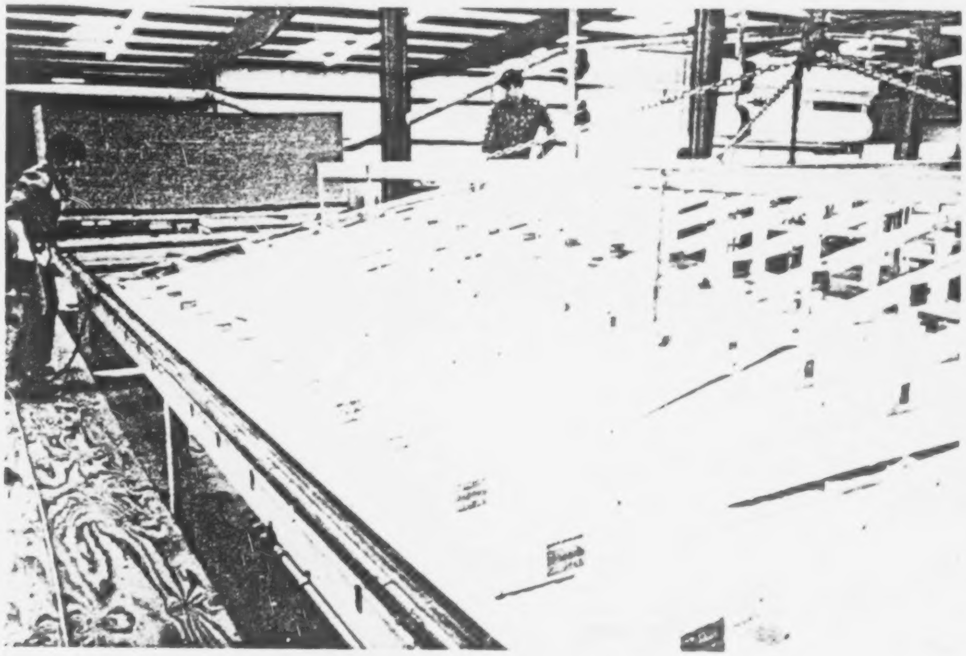
Figures 11 and 12

Construction of all homes in the United States today is a duplicative process since all types of residential buildings are made with 2x4 stud walls spaced 16" o.c. for all exteriors. These photos show typical production scenes in a mobile home plant. In the bottom photo, the worker is shown spreading glue on studs to which gypsum drywall or wood paneling will be glued and nailed. This is how a HUD-Code home wall achieves a major portion of its shear strength from external glue nailed sheathing, which the mobile industry does not use. Production steps for mobile and modular homes within their respective factories are quite similar.

Figures 13 and 14

Since the Introduction of the Department of Housing & Urban Development Code for the mobile-home industry in 1976, most mobile homes today are insulated (or can be according to the customer's order) just as well as any other type of residential housing. One departure is seen in the lower photo, is that because of its Chevrolet price range, the mobile home will use 2x3 members in its mono roof trusses rather than 2x4's. Nevertheless, the roof system is engineered for that specific home in the specific geographic area where it will be delivered.





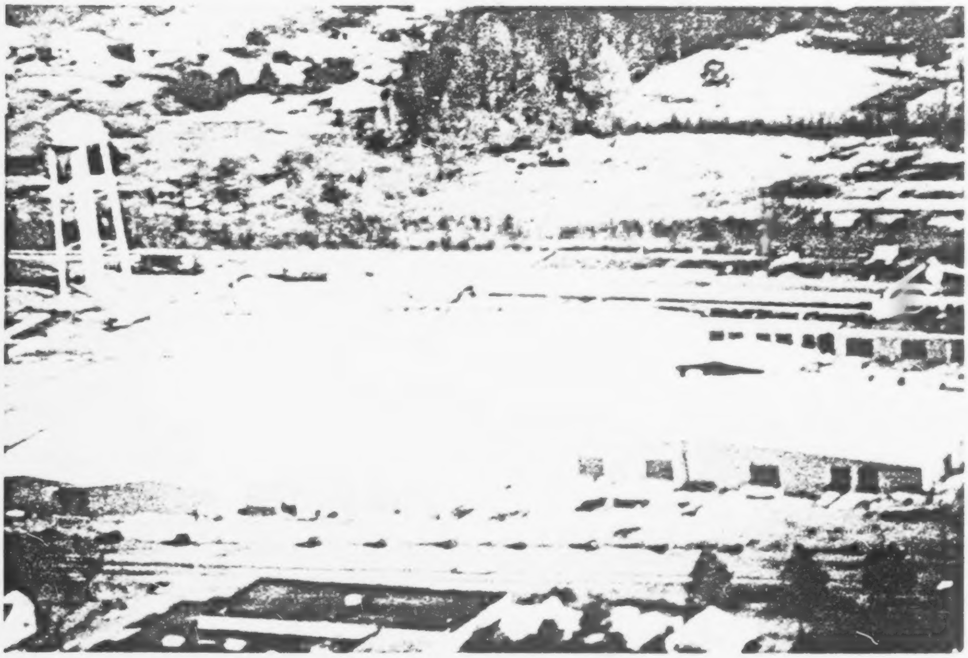


Figure 15

Aerial View of one of the nation's largest panelized home factories, Kingsberry Homes, Fort Wayne, AL, which is in excess of 100,000 square feet. Participants in the nation's panelized home industry number over 600, but range from huge plants of this size down to small retail lumberyards which panelize homes for preferred builders.

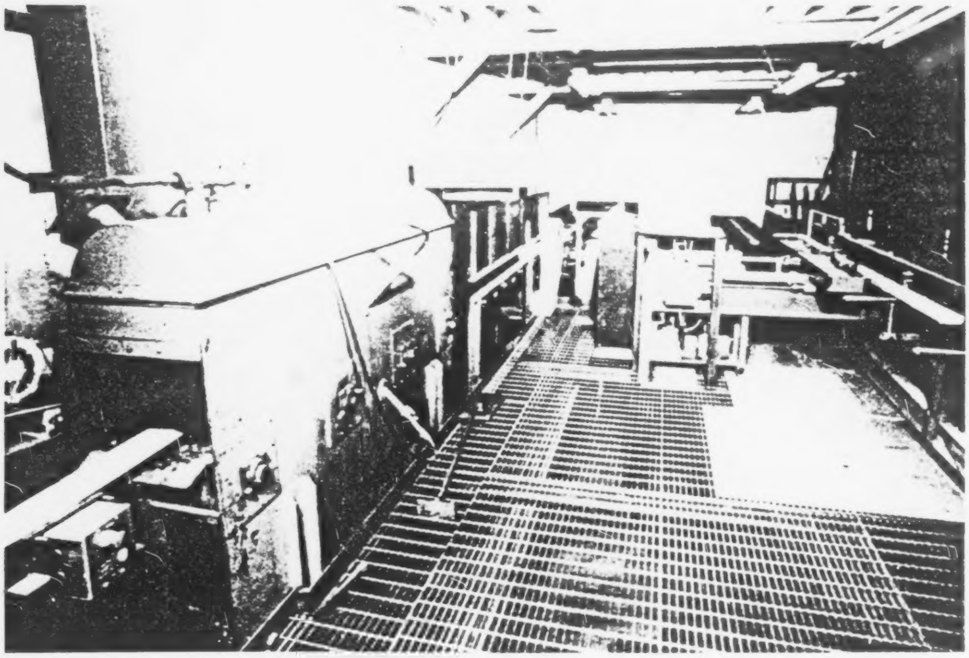


Figure 16

Non-Destructive Testing of lumber for strength qualities now is being performed by a number of lumber producers for the component industry. The independent component manufacturer, which makes major house parts for site builders, needs Machine Stress Rated lumber for critical roof truss projects such as nursing homes, commercial buildings and schools, and homes with unusually large clearspan trusses.

Figure 17

Floor Trusses, made of 2x4's and joined with metal connector plates on both sides of each 2x4 member, are now used in about 60 percent of U.S. homes and apartments. Floor truss actually is a misnomer because these 'flat-chord' trusses often are used for roof-ceiling systems.

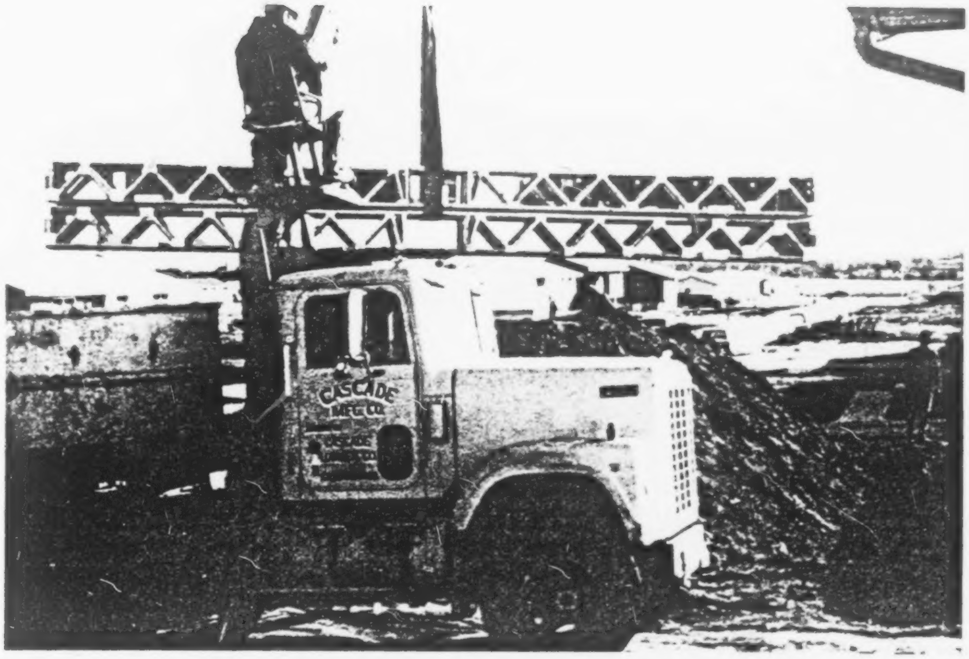
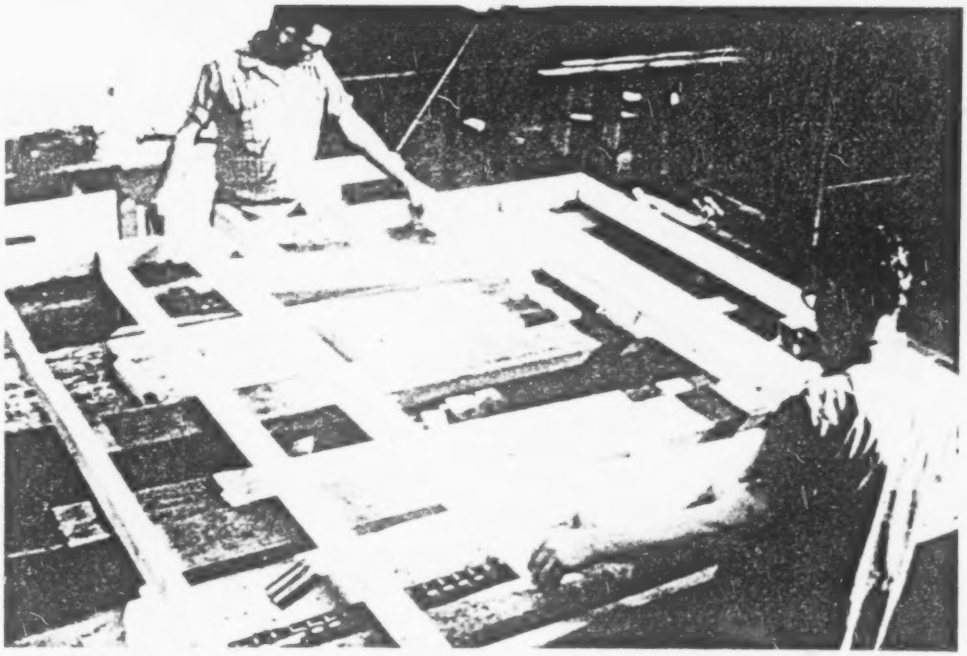


Figure 18

Component Manufacturers often assemble wall panels in the factory for use by site builders. Approximately 30 percent of the site-built homes and apartments utilize wall panels made by the nation's 1,800 component fabricators.



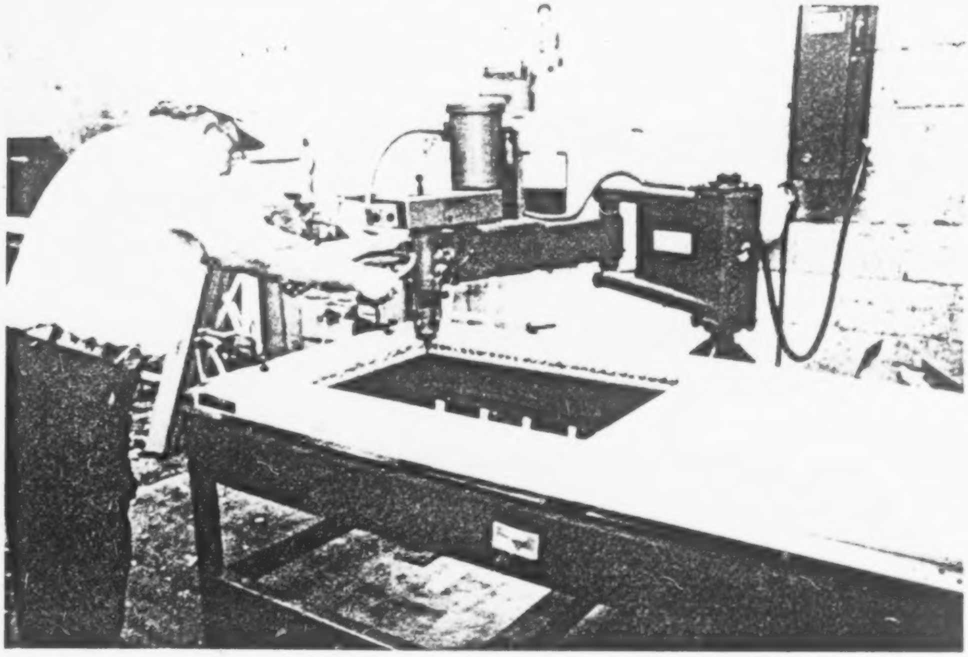


Figure 19

Component Fabricators also machine door blanks to order for production builders. They install the windows to order, put in the hinges, put in the lock sets, and pre-hang the door in its frame before delivery to the site builder.

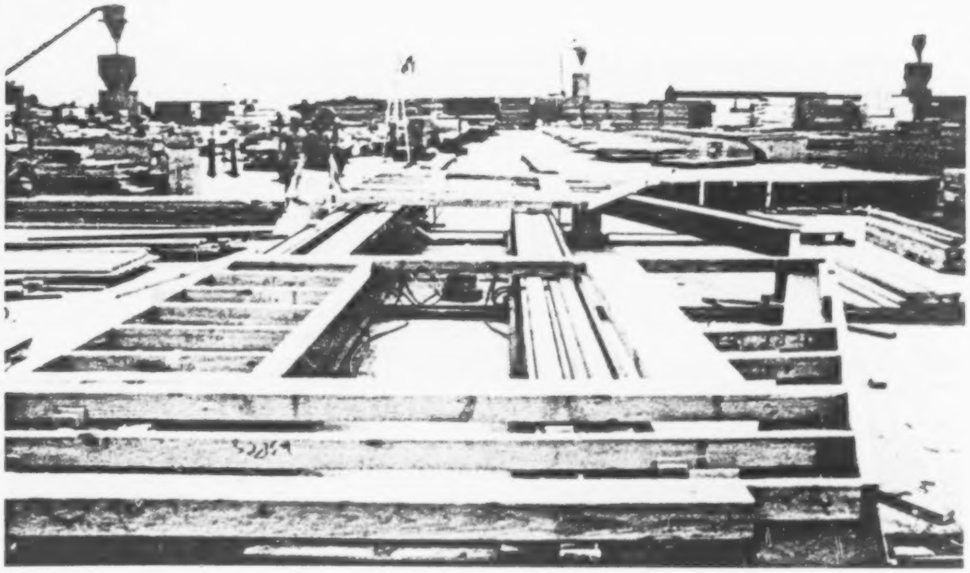


Figure 20

Wall Panel Machines used by component fabricators today are capable of making straight walls or gable end walls.

Figure 21

Component Fabricators are among the most sophisticated in terms of machining, and many use high-speed component cutters (saws) as seen in this photo which are capable of five angle cuts on the ends of 2x4 members at the rate of 60 pieces per minute. In-plant quality today far exceeds quality at the job site.

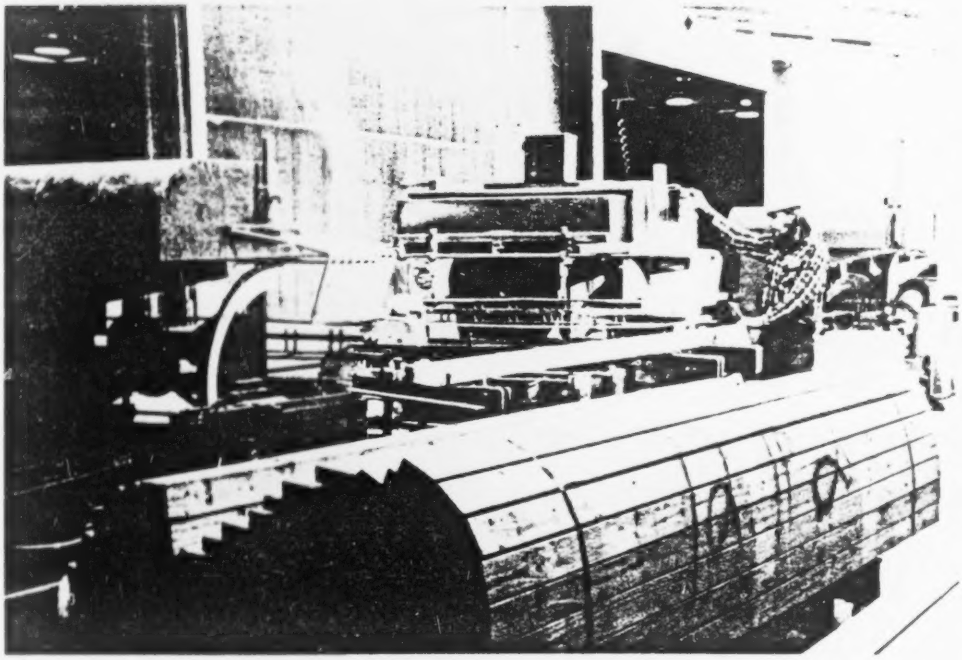
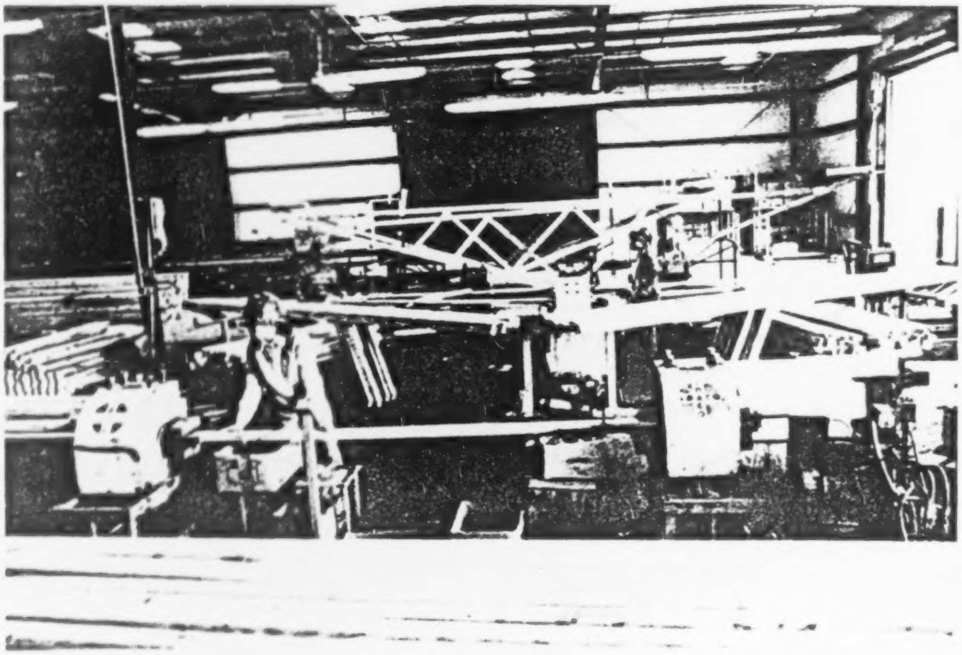


Figure 22

About 95 Percent of all component fabricators make roof trusses, and this is a mirror of the roof systems for single family homes and apartments in the U.S. today. These triangular trusses all are engineered for the specific in a specific geographic area by computer.



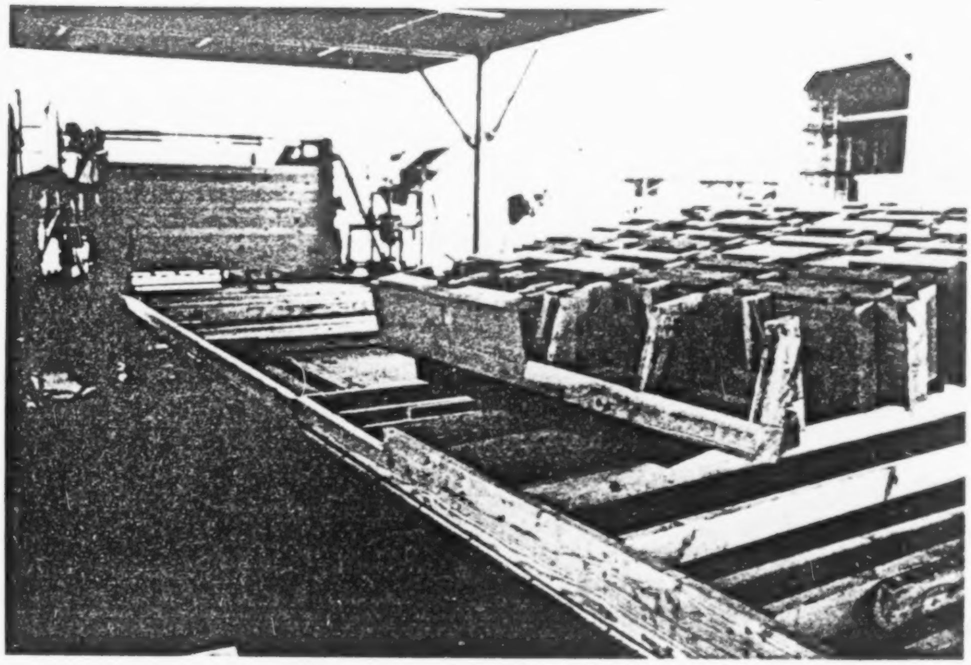


Figure 23

Some Component manufacturers use computer-driven, high-speed Kellner wall panel machines which are capable of turning out walls for a 1,800 square feet, 3-bedroom house in less than three hours.

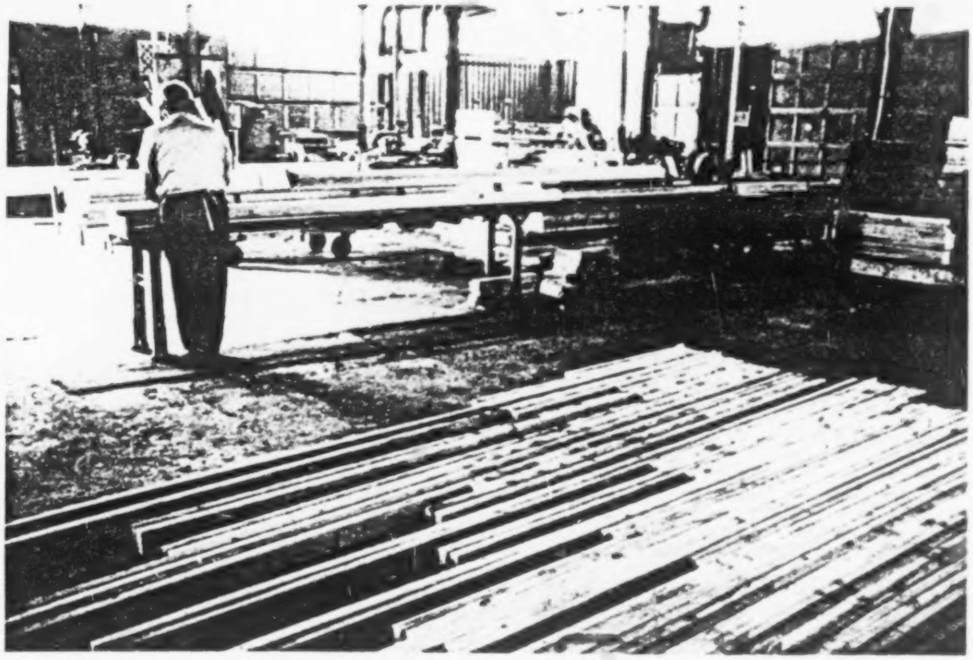


Figure 24

All Styles of in-plant home builders today use simple or elaborate cutting departments to prepare members for wall panels, roof trusses and floor trusses.

Figure 25

A Typical wall panel production line for either a component plant or a panelized home manufacturer may consist of a steel-topped or wood-topped production table with roller conveyors on both sides. Some wall panel machines are totally fabricated of steel, and contain lugs to hold 2x4 members in position while they are pneumatically nailed. When a wall is finished on one side it is said to be built by an 'open-panel panelizer'; when a wall is finished on both sides (and has plumbing and electrical inside) it is said to be a 'closed-panel' panelizer.

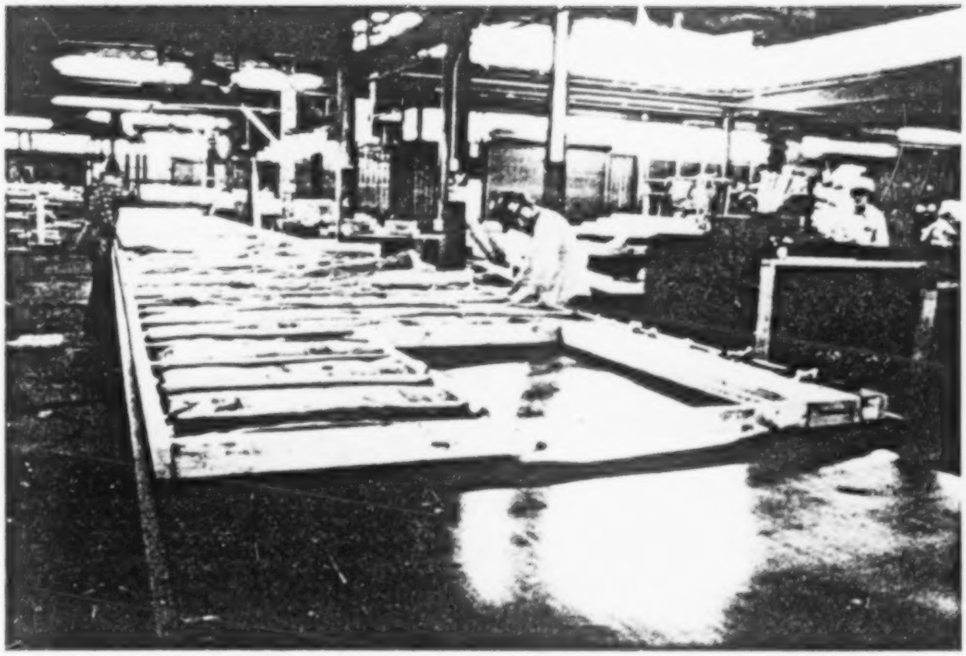


Figure 26

Mechanical Core Structures are made by both panelizers and component plants. The self-contained structures have a completely finished bathroom, the hot-water heater, the furnace, electrical junction box, and sometimes the wet wall for the adjoining kitchen. By doing all of this electrical and plumbing work inside a plant, the in-plant producer can save from $300 to $1,500 over the cost of plumbing and electrical work done at the site. In construction, the mechanical core structure is placed on the deck of the home or the concrete slab first, then the panelized home is erected around it.

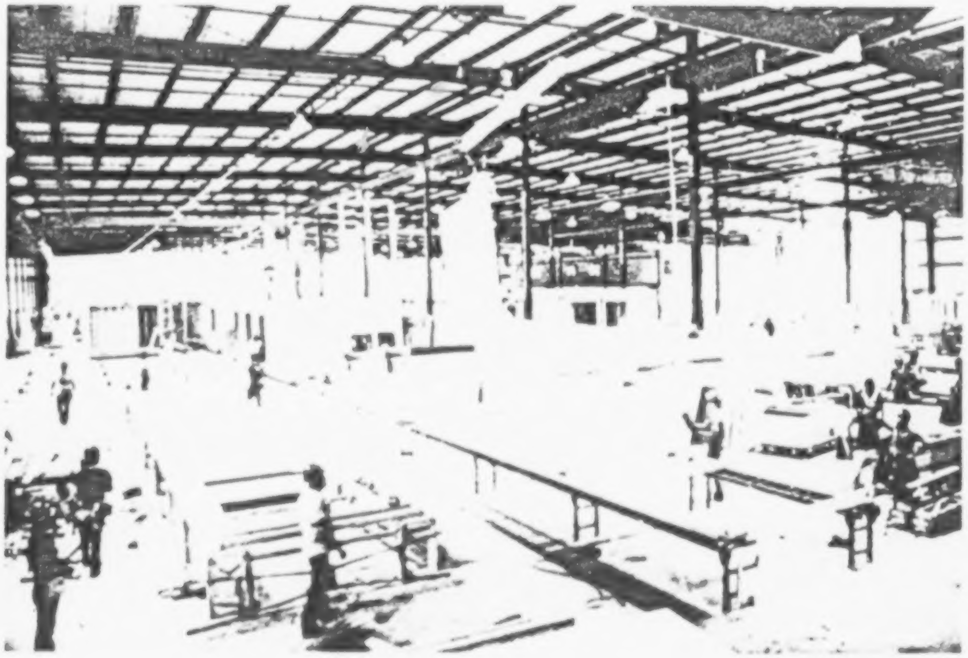


Figure 27

More and More Plants today are multiple purpose plants. This factory in Austin (Georgetown), TX, produces both modular units and panelized units.

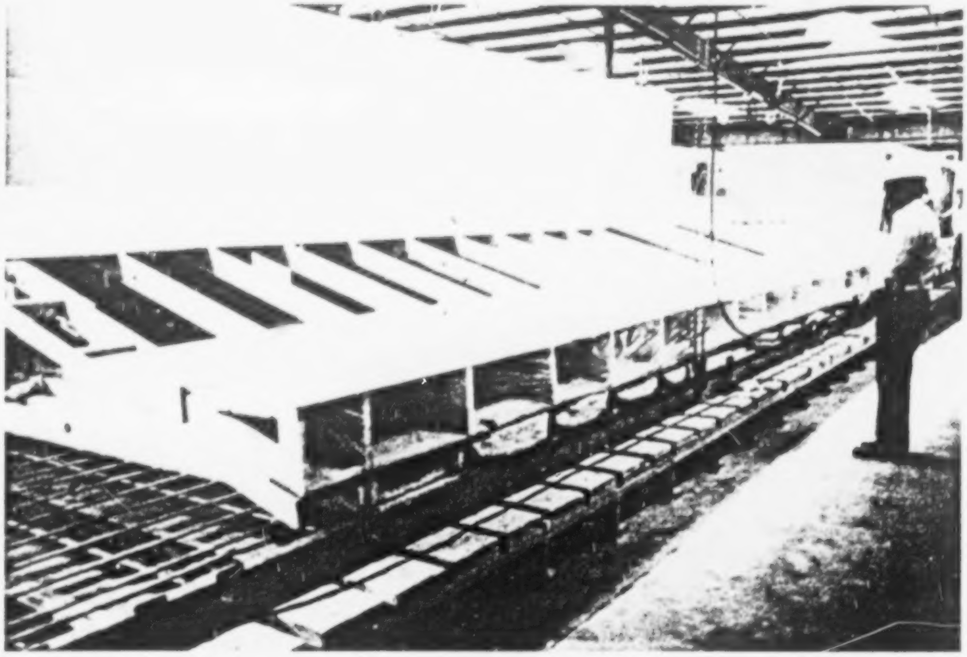


Figure 28

Jigs Are Used in both mobile and modular plants for fabrication of complete 'half-house' ceiling systems, which when complete, are transported by crane to the house production line and set in place on top of the half-house box.

Figure 29

Some Modular Plants build their homes with both sections joined together to insure perfect fits. At the end of the production line, the two halves of the house are split apart for transport to the job site. All modular homes are heavily sheathed with plywood, and they usually are built with unusually heavy floor decking and roof sheathing.

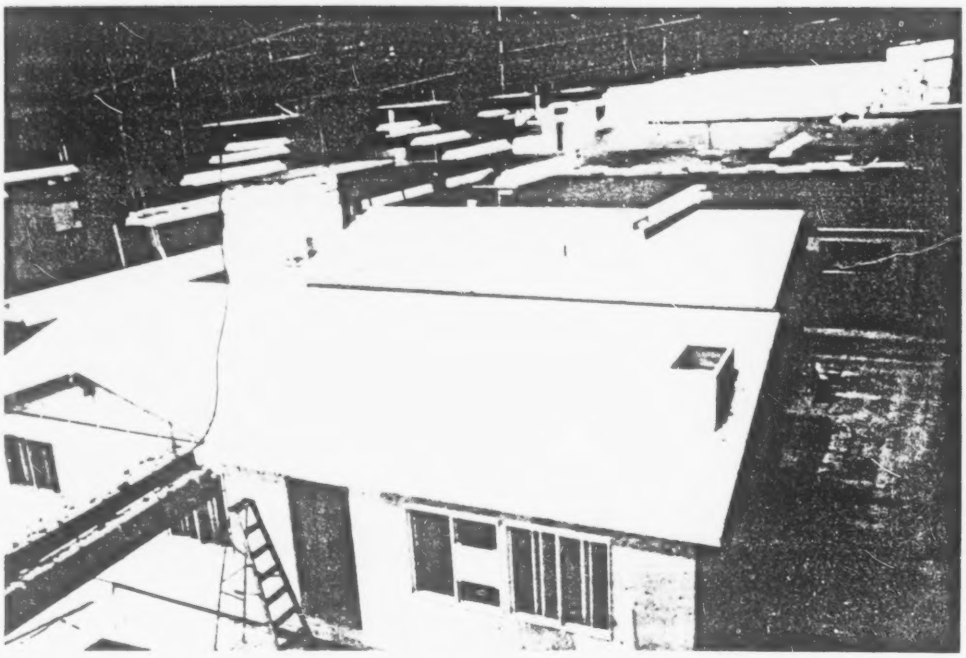
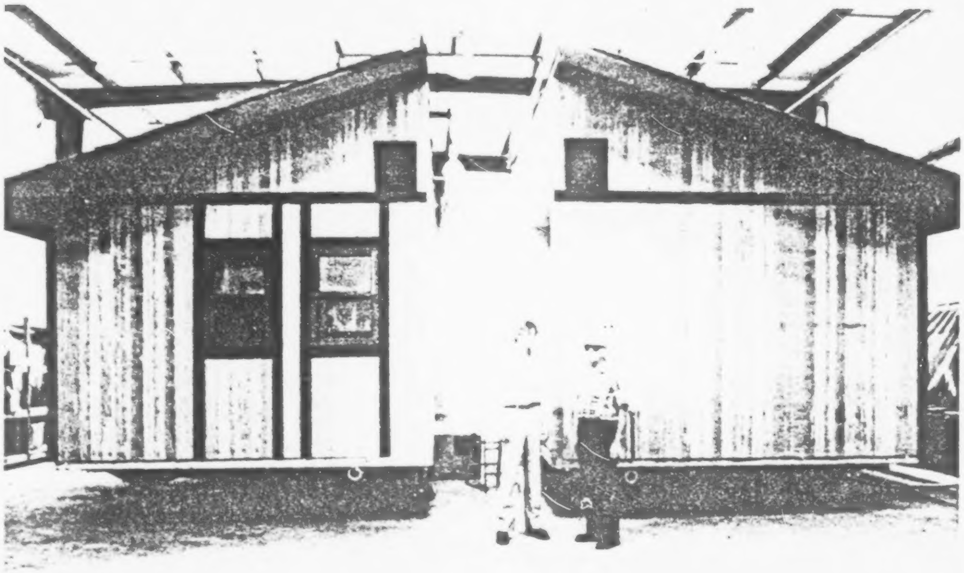


Figure 30

A Small Office Building, built to resemble a home but partitioned like an office, was built in a mobile home plant in San Bernardino, CA, in eight days. Its wood foundation was placed in the ground in one day, and the building was set on the foundation in one day. This structure could have been occupied in less than three days after delivery to the site.



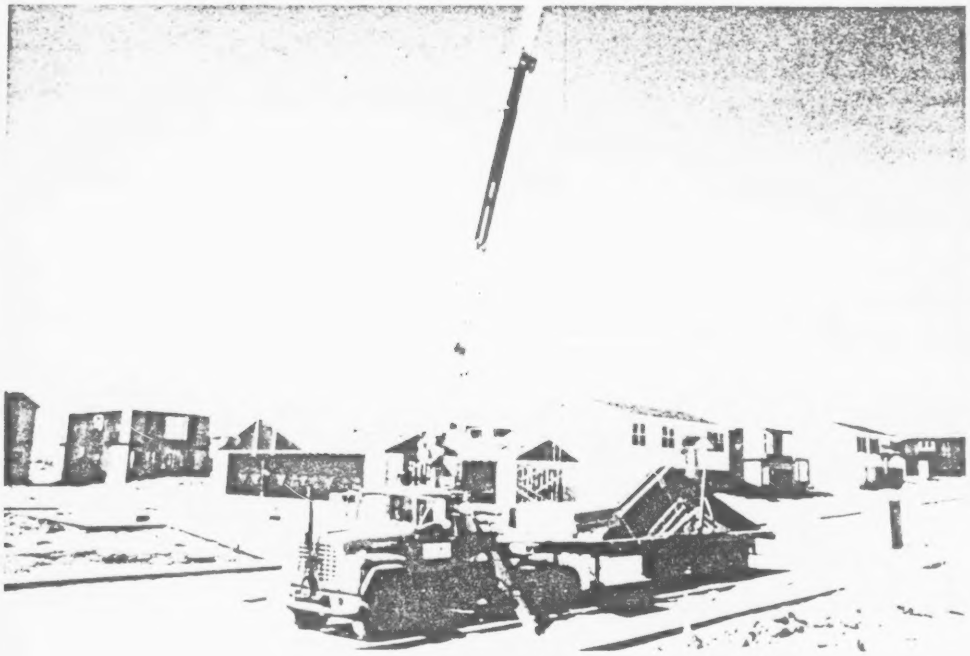


Figure 31

Many of the Nation's component manufacturers located near metropolitan centers sell their major house parts 'erected.' Thus, by the time the last component truck leaves a job site for a site builder, the floor trusses are in place, the walls are in place, the roof trusses have been added, and the home has been completely sheathed, or weathered in. The builder at the site then can take as long as he wishes to finish the house at the site using site subcontractors.

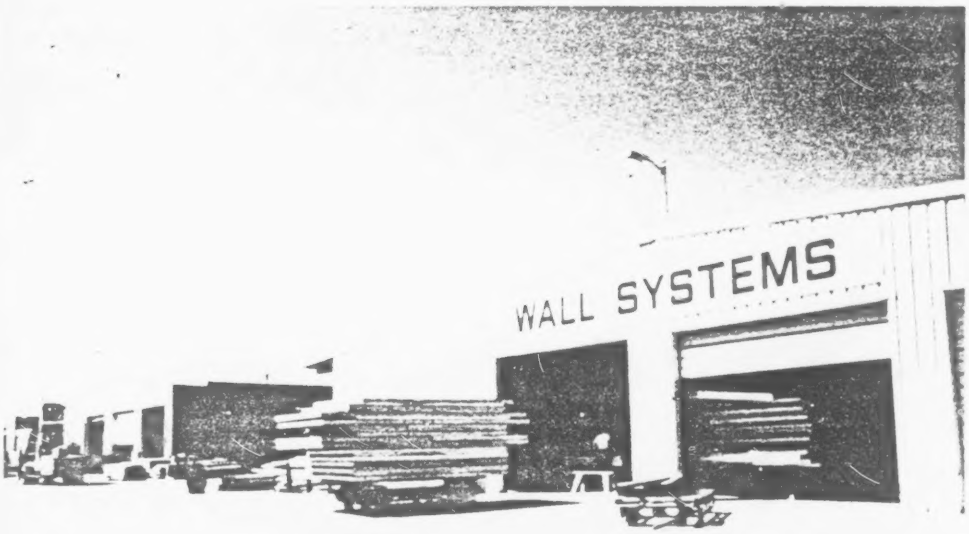


Figure 32

Many Component Fabricators, such as this one in Ogden, UT, have separate buildings for the production of wall panels, floor trusses and roof trusses.

Figure 33

The Setting of modular homes frequently is done by crane. It is also fairly routine to set mobile homes by crane, providing space is available. By having these half-house sections completely finished inside a factory, the 'cosmetic and stitching up work' to be done at the job site usually can be handled in less than one week, and the family can move in quickly. The speed saves considerably on construction interest loan costs because of the much faster occupancy time at the site.

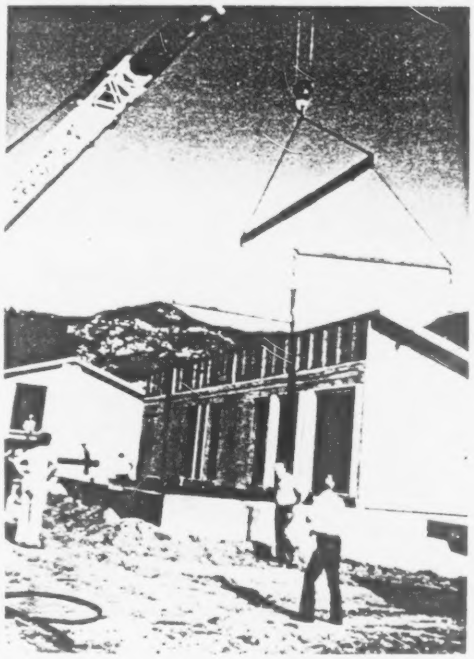


Figure 34

This Is Where the modern U.S. housing industry got its start. The invention of the 2x4 or 'balloon' framing system in Chicago in 1833 made America a nation of homeowners.

Eric Dluhosch

It is encouraging that the impact of technological change on the building industry is receiving national recognition and Congressional attention. The question is: Why now, and why the focus on building technology?

Clearly, there must be a feeling of uncertainty about the future performance of this important sector of the American economy, called the building construction industry, which according to the *Report of the President's Committee on Urban Housing* was expected to produce enough new homes between 1968 and 1978 to 'provide a decent home for every American family' during that decade. The dream of an *affordable* decent home seems to be receding, rather than becoming reality. For this reason alone, it is good to meet here and look at the problems of change and innovation again. For, in the meantime, we had Operation Breakthrough, the energy crisis, and the effects of technological change on the steel and automobile industries. If one adds to all this the many changes in American life styles, and continuing demographic age and geographic re-distribution of the U.S. population, and the incipient entry of Japanese and European home manufacturers in the U.S. market, uneasiness may easily turn into alarm.

The fact that we are meeting here, and the fact that the problem has been recognized as worthy of national attention, brings hope that a state of alarm can be avoided, and that lessons have been learned from past mistakes, and that another 'crisis' situation can be avoided.

If there is indeed an uneasiness about the future of the building industry, the first question to be addressed is whether we are, in fact and as a matter of perception, dealing with a *bona-fide* manufacturing industry, or whether it may not be more useful to regard the home-building industry as a *service industry*, since it is the home-building industry which I wish to discuss. In many respects it is indeed similar to many other service industries, such as health, education, recreation, and communications, for the home building industry delivers much more than just a short-term consumer product. Beyond building houses, it is inextricably involved in providing a host of other services, from financing to financial security, from status to ostentation, and from despair to pride. For the remainder of this discussion, and in order to provide a better conceptual frame for the following suggestions to be made, I will proceed on the assumption that home building is indeed as much of a service than a product, and that it acts as such in an *integrated* and highly coordinated manner in providing a host of specialized services, regardless of the fact that it may be regarded as highly fragmented as a production industry. This makes it also possible to neutralize the perennial controversy of fragmentation vs. integration, and also makes it much easier to look at technological change as a subservient aspect of service, rather than as the purely technical calculus of production efficiency. Technological change per se may thus be viewed as secondary to the achievement of desirable and/or feasible human goals, rather than as a quasi-autonomous end product. Beyond that, the assessment of change, if related to service, allows a more inclusive definition of technology, i.e., the inclusion of 'soft' technologies as an equivalent partner to past overemphasis on 'hard' technologies.

Thus, if the operations of the home building sector are viewed as a continuum of multi-faceted but integrated services, it is not only possible, but necessary, to include such 'soft' technologies as planning, programming, design, management, scheduling, procurement, and general goal setting and decision-making in our considerations. Institutional constraints can be legitimately factored in as part of the service mission of the housing sector, and questions such as the environmental impact of housing and quality of various life-style options can be linked to qualitative as well as quantitative strategies for the deployment of concrete 'hard' technologies (products, materials, systems, and assemblies). Based on the imperatives of service, technology assessment of hardware avoids limited definitions of what may or may not be assigned to a narrowly defined construction sector, thus allowing for the transfer of both techniques and products from the 'outside.' The intention is to break out of existing conceptual cages, and to broaden the scope of the discussion to include experiences and opportunities offered by all emerging and new technologies, regardless of their origin, while keeping in mind the ultimate goal of a quality environment for all citizens, with least damage to be inflicted on our already strained natural resources.

Keeping the above in mind, what then are the major technological changes which have had an impact on housing? Is there a new and different way in which we plan, design, procure, and assemble our houses today that is different from that of a few decades ago?

I submit that indeed changes in home building techniques and materials have been extensive and significant, even though, on the surface, the actual appearance of the average American home has changed very little. There are two reasons for this: the first is the nature of the product, the house, as a symbol of social stability and financial equity; and the second has to do with its long-term life as an investment asset tied to land and location. Real change has occurred, however, in the way the house is being put together, or, to use the proper technical term, *assembled*. Here major changes have affected the selection of substitute materials, the introduction of mechanized equipment and hand-held power tools, the delivery to the site of prefabricated components and assemblies, and the substitution of traditional fasteners, such as nails, staples, nail-plates, glues and zippers.

In that sense, the industry has learned its lesson well as an aftermath of the failed expectations of Operation Breakthrough to create a viable mass market for fully-prefabricated modular units by large quantity producers on large sites. In general, the trend has been away from so-called 'proprietary' or 'closed' systems, towards a more evolutionary (and more orderly) emphasis on highly-rationalized sub-systems, components, and elements, produced under controlled factory conditions, and supplied at controlled cost and quality.

In addition, the disappearance of large tract developments in the seventies has forced producers to serve a more diversified market of scattered sites distributed over larger geographic areas. This has led to more careful considerations of ease of transportation, handling, and product customization in assembly.

Let me list some of the more dramatic changes which have occurred along these lines:

Planning and Design

- More compact site planning, with savings achieved by providing better planned and less wasteful infrastructure services (i.e., sewers, water, power, and communications).
- Introduction of new dwelling types for new life-styles such as cluster housing, zero lot line zoning, 'theme' villages, garden apartments, condos, and other 'specialty' types.
- Better space utilization by more compact plan layouts, and the combining of functional spaces into lofts and galleries, including the provision of unfinished spaces for future expansion.
- Better understanding of energy saving systems as part of integrated design packages, using design as a means to minimize energy consumption. This includes both active and passive systems, such as solar heating, tromb walls, insulation sandwiches, atriums, solar greenhouses, and many more.

All of the above-listed developments have generated new markets for new products, such as 'life-style' supermarkets for do-it-yourselfers, TV home-improvement programs, and new magazines for yuppies and other new life-style groups. New home owners have become more sophisticated in their understanding of the way their homes are constructed, and thus may be expected to demand better quality and higher performance from their houses in the future as well.

In terms of new techniques, the gradual introduction of low- and medium-cost microcomputer systems in the design of housing has led to the establishment of national as well as local data bases, readily accessible to professional and layman alike, thus allowing both access to a wide range of services, product catalogs, and other related life-style information.

The linking of computer-aided design programs with compatible software, with the capability of almost instant energy calculations, cost estimating, inventory checking and designoriginated production control of automated machines, has made it possible for the first time to control the entire process by means of fully integrated design-decision programs. Thus, decisions made in the design office can be electronically linked with inventory and cost control, procurement, as well as controlling production in the factory, scheduling assembly on the site, and delivering a customized house, as per specifications, at a guaranteed cost to the home buyer. In addition, the increased memory capacity of the new generation of microcomputers allows for simulated or real-time testing of alternative designs in terms of cost, production ease, and customer acceptance. Given this capacity to manipulate and combine, standardization by repetition becomes redundant, since it is now possible to program the computer to take cognizance of complex and/or sophisticated compatibility rules for dimensional and/or positional coordination, without necessarily repeating the end product. This promises more, not less, design freedom in less time at equal, if not lower, cost to the end user.

As an extension of the above, it is now technically feasible, both in the U.S. and to an even larger extent in Japan, to combine computer-aided design directly with the sales office, where the customer can actively participate in the design of his or her future home plan and at the same time get instant feedback on cost and delivery.

Many of these innovations have been introduced piecemeal and, more often than not, were developed independently of each other and on a limited application basis. It is now becoming evident, especially in view of the Japanese example, that a fully-integrated, computer-aided system which covers all aspects of decision making from design to erection is not only feasible, but virtually inevitable. This, in turn, will significantly affect the entire practice of design. An opportunity will be provided for the designer to again become a true 'master builder,' since he or she will be able to assess the consequences of each design decision on every aspect and phase of the total design-delivery process, rather than having to depend on time-consuming and indeterminate processes of delegated control. The impact on design-office organization, professional decision-making roles, and education is yet to be assessed, but surely will be dramatic.

Beyond that, the capability of computer-aided design-delivery systems to communicate with each other may be expected to have an equally dramatic effect on all other aspects of decision-making in the construction industry, both in terms of horizontal and vertical communication flow, to wit:

Horizontal:

- Quick access to powerful local as well as national data-bases on a fee-for-service basis (e.g., Specwriter, AEPIC, etc.)
- Nationally coordinated and periodically updated catalogs of products, assemblies and entire home packages, including performance and cost data (e.g., a Sears catalog of building)
- Linkage between electronic-specification data bases, testing, and code administration. For example, a given design can be matched by entering its specification 'profile' into a code-checking program, to give the designer instant feedback on code violations or alternative code-compliance rules
- Electronic control of inventories, linked to cost and availability
- Customized, as well as automated, production control
- Robots for productivity and quality control
- Positive cost control and accurate quantity estimates, linked to design
- Testing and comparison of alternative design solutions against all or some of the above.

Vertical:

- Elimination of 'back-of-the-envelope' bidding
- Bidding based on combination of best or least expensive modular packages, rather than lowest overall estimate
- Direct end-user input into design process, allowing simulated as well as real customization of plan, linked to instant cost estimate of desired solution
- Time-lapse monitoring of energy consumption as part of budgeting home-maintenance ex--penses
- Scheduled operation and maintenance routines as part of electronic home-control systems

- Full-service professional services that are integrated both horizontally and vertically and are multi-disciplinary. Elimination of division between design and production.

Product/Process

- Substitution of cheaper and/or better performance products, with better characteristics in terms of handling, connections, interface and maintenance ease
- Substitution of hand tools by power tools, and eventual transfer of most conventional site operations into the factory
- Introduction of computer-controlled machines in production process. Increased diversification of end product
- Introduction of robots, both in production and in the home
- Gradual shift from 'constructing' a house by means of semi-processed and extensively site-modified materials to fully-processed and precoordinated elements, assemblies or entire modules. Elimination of waste in cutting and other manipulations on-site.

Some examples of products or processes now on the market:

Materials:

- Annular ring- and spiral-shank nails
- Single-layer siding/sheathing
- Improved paints
- High-pressure, melamine-laminated, countersurfacing materials
- Prefinished siding
- Stress-rated lumber
- Self-sealing shingles
- Epoxy coatings for plywood
- Polyethyline vapor barriers
- Rubberized/plastic, single-sheet roof membranes
- Hardboard roofing panels
- Fiberglass insulation blankets/sheets
- Prefinished large ceiling panels
- Prefinished tapeless, vinyl-covered, gypsum drywall
- Resilient tension flooring, applied without adhesives and stapled only at edges
- Solar-film window glass
- Vinyl-extruded window sash.

Assemblies:

- Split-ring trusses
- Component wall panels (stapled or glued)
- Wall-hung closets
- Prehung doors and windows
- Pre-fab stairs
- Wood foundations
- Fiberglass modular bathrooms/showers
- Raised bathtub assembly with above-floor trap
- Washerless faucets
- Single-vent bathroom plumbing
- Snap-on pipe connections
- Water-saving faucets, toilets, and shower heads
- Compressed-air-assisted toilet flush
- New air-to-air heat exchangers
- Self-diagnosing appliances.

The above list is far from complete, but is offered here as a sample of the rich variety of new products and assemblies which have entered the market since Operation Breakthrough. The impact of these innovations on all aspects of construction practice is both subtle and all-pervasive. There is a clear shift from traditional 'craft' skills to industrial-type 'assembly' skills, even on-site. In general, no work that can be handled mechanically (with some rare exceptions, such as brick laying), is done manually. There is a parallel tendency to reduce the number of joints by larger basic elements, and to manage jointing operations as much as possible from the factory. Joints constructed on-site are more accurate and tighter due to power hand tools, better joint compounds, joint fillers, and cover strips, all of which promise easier maintenance (as well as better performance) and mean less or minimal maintenance. Diaphragm construction permits the use of thinner wood sections and wider spacing of framing members. The list goes on. As a consequence, homes are put up much faster and require less labor input per unit. Quality control has shifted, to a large extent, from the site to the factory. This has serious implications on inspection and code enforcement. In fact, the whole system of code administration and enforcement is due for extensive revision and will rely more and more on computerized data banks and mixed material/performance specifications.

Training of construction labor will require a new approach to specialized skill development, as well as periodic retraining in mid-career.

Unions will have to cooperate in negotiating new trade responsibilities, options for trade integration, and a certain degree of skill reorientation on a continuing basis.

Current distinctions between designer, developer, contractor, and producer will become blurred, with integrated 'full-service' organizations — teams providing comprehensive design-to-delivery services, possibly including financing and periodic upgrading options.

As a service sector, construction will rely on materials from both traditional construction supply sources, but also from formerly non-construction-oriented industries, such as electronics, plastics, fabrics, etc.

New specialities, such as geodesic domes, space-frame structures, inflatables, and fabric/tension structures are already entering the market as mature industries and are expected to invade the leisure and recreation segment of the home-building market. Different skills in both engineering/design and production/assembly will develop as demand for these 'exotic' structures increases.

With the exception of the mobile home, the trend will be in the direction of 'open' or catalog component systems.

Emphasis will be on the development of 'foolproof' and easily maintained joints and connections, allowing easy installation and maintenance-free operation.

Factory production will continue to rely even more on computer-controlled machines and robots, and will compete with conventional construction for a diversified and customized market.

Craft skills will become part of a lucrative, but limited, market for retrofit, conversion, rehabilitation and historical preservation.

Houses will be sold with component warranties by manufacturers and may be financed by component mix rather than as a finished product.

The development of plug-in, zip-in, and hook-up connections for telephone equipment, and the use of plastics in plumbing, heating, and electrical equipment will ease maintenance problems, both in terms of currently outrageous service fees for even minor repairs, and as an integral part of self-monitoring devices, combined with home security, climate control and computer-controlled communication centers.

Much of routine maintenance will be performed on a do-it-yourself basis, with the possibility of linking computer-controlled monitoring systems with pre-recorded or locally broadcast TV do-it-yourself instructional messages. This will help the home owner to diagnose, as well as correct, minor failures or communicate for help with warranty service centers.

Impact on Policy

Historical experience has shown that innovation responds to change, and change to innovation, in most unexpected ways, and that it usually manifests itself first at the interface of the frontiers which appear on the horizon of our expectations. If we fail to search for signs of change on the horizon of our hopes and expectations, crisis usually forces change and imposes innovation. Much of our past reaction has been a response to crises of various origins, rather than the expansion of our freedom to act. Operation Breakthrough has been mentioned before and may be seen as a reaction to the housing 'crisis' of the sixties. The energy embargo of 1973 precipitated another 'crisis.' Few of us who have devoted years of our professional lives to the 'solution' of these crises have continued to receive support for continuing our efforts, even though the 'crisis' may have lapsed. Indeed, we are asked to respond to new emergencies, to study new problems, to re-tool for new research. The tragedy is not that these projects have failed, for they have not — at least not entirely — but the cost at which their limited success was purchased.

Thus, after having responded every five years to a new 'crisis,' it is my humble opinion that we do not need or deserve another 'breakthrough' or another heroic 'if we can put a man on the moon' effort.

What we need most is genuine continuity and the removal of unnecessary institutional barriers and restrictions, which have stunted sustained efforts to take the long view of things, and which impede the ability to carry experiments to their full maturation, including the chance of failure.

Since innovation by its very nature is impossible to predict — for then it would cease to be perceived as true innovation — it may be more useful to remove existing constraints which prevent us from breaking out of present conceptual cages and to develop a climate of confidence for long-term institutional as well as private centers of excellence, which may or may not invent new gadgets, but which will act as powerful intellectual and technical brain trusts, and whose members will act as a vital source of basic knowledge and understanding for both government and industry. The former to act as a facilitator, the latter as producer. In concrete terms this implies:

- Agreement on long-term national goals, beyond party or factional concerns;
- Assurance of long-term support for so-called centers of excellence in universities and not-for-profit think tanks;
- Removal of institutional barriers, restrictive rules, and bureaucratic interference with long-term research and development;
- A clear mandate for short-term initiatives and research, without false promise of long-term and sustained support, if not expected or likely to be forthcoming;
- Clear allocation of responsibilities and commitments to research and development between government, industry and the universities;
- Monitoring of objective assessment of new technology as to its side effects, and in relation to long-term goals
- Removal of conflicting jurisdictional rules between local and national levels of government
- Non-adversary partnership between government, industry and universities
- Review of all restrictive zoning, based on new technical and life-style conditions
- Operation and maintenance of urban infrastructure systems made independent of discontinuous political mandates. Establishment of minimum quality standards and technical performance criteria for capital investment in the public sector
- Short-term policy cycles to be coordinated with long-range national goals
- Appointment of 'technology watchers' both domestically and abroad (based on Japanese precedent). Regular reporting to Office of Technology Assessment
- Establishment of national data base and information exchange for construction technology advancement and dissemination of research results and reports by technology watchers
- Establishment of regional construction technology centers, say on the model of Dutch Bowcentrum, including affiliated continued training and education programs
- Set up bonded warranties for new products and processes to be introduced in market for testing purposes
- Upgrading of equipment in trade schools and universities.

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5

Energy In Buildings

David E. Claridge
John P. Millhone

David E. Claridge

Overview of Building Energy Use and Economic Importance

I will begin with a brief overview of the economic importance of energy use in buildings. This somewhat overlaps John Eberhard's presentation but has a different emphasis.

Consider the items that directly affect energy consumption in a typical commercial office building. These include the electrical and mechanical systems, lighting, elevators, insulation, upgraded windows, and measures to reduce air leakage. The cost of these items will vary from building to building, but will typically be one fourth to one third of the cost of the building. Thus, the construction cost of energy-related aspects of a building is a very significant fraction of the building cost.

The energy to operate a building typically costs fifty cents to two dollars per square foot per year — perhaps ten percent of the total rental cost. These two items will thus contribute 35 to 40 percent of the total cost of owning and operating a building.

The cost of energy used in U. S. buildings is approximately $150 billion per year or about four percent of GNP. This is essentially equivalent to the gross farm income, so we spend as much for the energy used by buildings as the income generated by all farming activity in the United States. Everyone recognizes the importance of the agricultural industry to the country, but the magnitude of energy use in buildings is not so widely recognized.

I don't have hard numbers on the building construction employment due to the energy-related systems and components, but it must exceed one million jobs. I have examined engineering employment in the energy systems area, and it appears that about 100,000 engineers work in all facets of the HVAC (heating, ventilating and air conditioning) field including equipment design, equipment sales, building systems design and specification, etc. Energy-related employment in buildings is clearly a significant factor in the national economy.

The importance and overall economic impact of energy use in buildings depends on how it is measured, but it is obviously more than one percent and probably about five percent of GNP. This is a significant factor in the national economy.

Energy Retrofit: A Case Study

There are a numerous developments and topics regarding building energy systems that could be discussed. I will illustrate an important point with a short case history.

We recently studied energy use and potential measures to reduce use at the student recreation center at the University of Colorado. The University spends about $250,000 per year on all types of energy for this 150,000 square foot building. A number of steps had been taken to reduce energy use in this building subsequent to an earlier study of the building. One classic measure implemented was rescheduling the janitors to clean during operating hours instead of at night when the building was closed. This saved $25,000 per year in lighting cost. A related measure was delamping to further reduce lighting energy use. Insulation was added to make the locker rooms below the ice rink more comfortable, reduce their heating requirements and decrease the refrigeration requirements of the ice rink. A heat recovery system was added to the brine chillers to preheat hot water and improve the system efficiency.

These measures resulted in savings of about $50,000 per year, but this year's study found a large number of additional measures which can save an additional $70,000 per year for an investment of $70,000. Many of these measures were again very typical.

Outdoor air sensors are used to control baseboard radiation heating in the swimming pool area. These sensors were 11°F out of calibration. It is estimated that recalibration at a cost of $100 will save $5,000 per year in heating cost.

The usage recorded by a gas meter which meters clothes dryer consumption exceeded the rated consumption of the dryers operated 24 hours per day, and they are used less than 8 hours per day.

Interestingly enough, many of the fixtures that were delamped two or three years ago were fully lamped this year. The lamping crews had replaced all of the delamped tubes on their next pass through the building. The ballasts must be disabled to ensure that the building will stay delamped.

Reducing the exhaust air from a number of the building zones will show immediate benefit. Many fans continuously exhaust conditioned air. We also found that a pool cover would save several thousand dollars a year — and this isn't so typical, simply because few buildings have swimming pools. There were a number of other similar energy-saving measures identified which I don't have time to discuss now.

The major point illustrated is that (with the exception of the pool cover), every measure recommended by the current energy study was a change in building operation or an improvement in the energy-using systems within the building - not a change in the building envelope or configuration. This is typical of the majority of the opportunities for reducing energy use in the commercial building sector.

Recent Trends

Recent trends in new building construction show a major increase in the number of installations with variable air volume systems. Reheat systems are not nearly as common as they were in the past. Variable speed fans and motors are now being used in some buildings.

There have been numerous equipment improvements in the residential sector. The same is true in the commercial sector. Improved compressors and chillers are widely used; heat recovery from exhaust air is no longer a novelty. This morning we heard about new computer applications in buildings. The level of control which is possible today is much more sophisticated than was available only a few years ago. And this will continue to improve.

The use of unconditioned outside air for cooling when temperatures and humidity permit, so called 'economizer cooling,' is an extremely elementary concept; but it was very seldom used ten years ago. Today it is commonplace. The use of chilled water storage to permit use of off-peak power for cooling is not yet commonplace, but it is no longer a novelty.

Cogeneration of heat and electricity was widely studied and discussed in the late 1970s, but was seldom used. Recent improvement of the natural gas supply situation has sparked further interest. Cogeneration is now actively marketed by gas utilities and is increasingly used.

Typical building shell improvements like insulation and better glazing are almost universally used. Further improvements will come in these areas, especially as high performance glazing systems are perfected and marketed. Passive solar and daylighting are sometimes used in commercial buildings. I should also note the improvement in electric lighting systems. Third-party ownership has led to a significant number of active solar installations on commercial properties.

While these changes have generally resulted in substantial (and sometimes spectacular) energy savings, they have had a relatively minor impact on the overall construction process. They do require a better understanding of building energy flows and systems by the architects and engineers who effectively and efficiently design buildings with low energy use, so the major change has been the need for improved design skills.

Future Trends

The last decade's improvements in building energy systems, equipment and materials will continue. Beyond these changes, I believe we will see increased integration of components and systems in buildings. The design process will require practitioners with a deeper understanding of building energy systems and flows *and* who know how to integrate HVAC systems and components with the other systems in efficient and functional buildings.

An example is inclusion of thermal mass to reduce energy use. You can seldom afford to add mass to a building based on reduced energy cost. However, if mass is planned for structural, decorative or other purposes, it makes a lot of sense to design so the building obtains a maximum thermal benefit from the mass.

We had a talk this morning about 'smart' buildings or 'intelligent' buildings. Building control systems will be much more than just energy system controllers. They will often handle security, life safety systems, communications, etc. The energy related aspects of these systems will expand to include control of daylighting, thermal integration, building tightness, indoor air quality, etc.

I believe that acceptance tests based on the use of expert systems will eventually become commonplace. As we all know, after a building is built, the architect and engineer walk away and seldom look at it again. We need to go beyond just designing and constructing the building. The design data should be used in conjunction with an acceptance test to let an owner know that when a building is accepted, the energy systems perform as designed. If they don't, the building won't be accepted until the problems are corrected. We don't yet know enough yet about building and systems performance measurement to develop comprehensive diagnostics immediately, but it will be possible in a few years.

A related development will be diagnostic testing for existing buildings. Such tests will use a more limited data base but will still be very useful for maintenance and will provide valuable information for prospective purchasers.

Rehabilitation and retrofit will be continuous for functional purposes as well as for energy purposes. Perhaps one of the best illustrations of this need is the Enerplex South Building near Princeton University. The Center for Energy and Environmental Studies at Princeton assisted the design team and is now monitoring the building — designed as a state-of-the-art building. Several cost-effective retrofit measures have already been identified for this nearly new building. Variable inlet fans are used in this building. Today, variable speed fans are viable. Installing variable speed fans, reducing the night thermostat setting from 58°F to 55°F, and increasing the supply air temperature from 55°F to 60°F is projected to provide an additional 21 percent reduction in the already low heating requirements of this building. Note that none of these items will change the environmental conditions in the building during occupied hours.

This example illustrates that even state-of-the-art buildings can sometimes be improved by system changes. Consequently, I don't believe that the existing building stock will be retrofitted and improved to the point where further retrofits are no longer needed after five years or twenty-five years.

We can expect increased automation of the entire design and production process. Increasingly powerful CAD/CAM systems will be used as discussed this morning and more buildings, assemblies and components will be manufactured.

The changes discussed will lead to improved building environments and improved building quality. Both will be increasingly important in future buildings. Cost-competetive techniques have been discussed at length and are important. However, note that Japanese automobiles are not cheaper than American automobiles, but they offer higher quality; and the American consumer has learned to appreciate and purchase this quality. This will affect future building purchases as well.

I expect these trends to provide an impetus for industrialized construction. Energy considerations will not single-handedly bring about industrialized construction, but will encourage this transition. Tighter buildings with less air leakage will generally use less energy, and it is clearly easier to achieve reliably tight construction with industrialized construction techniques.

Finally, I will note an issue of particular interest from a university perspective. These changes will require a more integrated design team whose members have better skills and better education than is generally available today.

This will require changes in university curricula. As a specific example, we've had a lot of recent input from leading practicing engineers who say that the education received by HVAC engineers is deficient. The basic and applied thermal sciences education received by the typical engineer entering the field is less than one semester of his total education. It has been stated that HVAC engineers take much longer to become productive than structural engineers and others. This area must be addressed by universities.

Conclusions

Observation of the energy-related changes in buildings during the last decade and consideration of projected changes indicates that:

- Energy-related changes in buildings will not require major changes in the structure of the building industries;
- Technical developments will continue to improve energy efficiency for the foreseeable future. The degree of change will depend on energy prices;
- Energy retrofits will continue for decades;
- Consumers will demand improved environmental and construction quality in buildings;
- Energy-related factors will contribute to the trend toward industrialized construction; and
- Universities will need to provide better engineering education in the building sciences.

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John P. Millhone

I'm going to discuss two topics. First, I'm going to talk about the energy use in buildings, covering both residential and commercial, to establish sort of a data base for this subject. Then I'll talk about residential energy use and what's occurring in that area. Dave will talk about commercial building energy use. We've made this split with the understanding that we occasionally waiver into each other's area because our interests are in both areas.

The office I head at DOE handles the regulatory and the research activities of the Department. Usually I find myself tormented by the regulatory parts of the job. So it's a great pleasure for me to be able to talk about some of the researching kinds of things, although we had gotten into some regulations.

The energy use in the building sector is about 26 quads, 16 of those in the residential area, 10 in the commercial area, and here you can see how the energy is used for different purposes in buildings: space heating, water heating, refrigeration dominates in the residential area; space heating,lighting and air conditioning in the commercial area. (See Figure 1).

In the residential building sector shown in Figure 2, here the six percent mobile home wedge refers to Don Carlson described as HUD-built, manufactured homes. When we talk about some of the modular and other manufactured portions of that market, that wedge would increase.

Figure 3 shows square footage of buildings rather than energy use in buildings. It indicates the diversity of different types of buildings, when we talk about the commercial building sector.

Now, what this means from a technical perspective is that there are a lot of different kinds of buildings that you are dealing with in terms of design materials or what have you when you talk about commercial buildings.

With that as the introduction, allow me to make a couple more points as far as energy use in buildings in the U.S. is concerned. The 26 quads represents about 36 percent of the nation's energy. The energy use in buildings in the U.S. has remained fairly stable during the past ten years in the 26 quad range. However, within that energy use, there have been some changes that are fairly interesting. Natural gas use has changed very little, gone down a small percent. Petroleum use has declined fairly rapidly, going from about 18 percent to about 10 percent. Making up that gap has been a fairly significant increase in electricity energy use in buildings, rising from about 50 percent to 60 percent.

The coupling that I think is starting between energy, the electricity use in buildings, and the electricity industry is becoming increasingly significant. As you know, a number of changes are taking place in the electric industry, and I think that interaction will be recognized as increasingly important.

As we look forward the gap between energy supplies and demand is expected to tighten during the last half of the 1980s and remain fairly tight during the 1990s, creating some upward pressures on prices. I hate to get into price forecasts, although we do some of that work, but I think that the pressure on prices will become more compelling during the latter portion of this period.

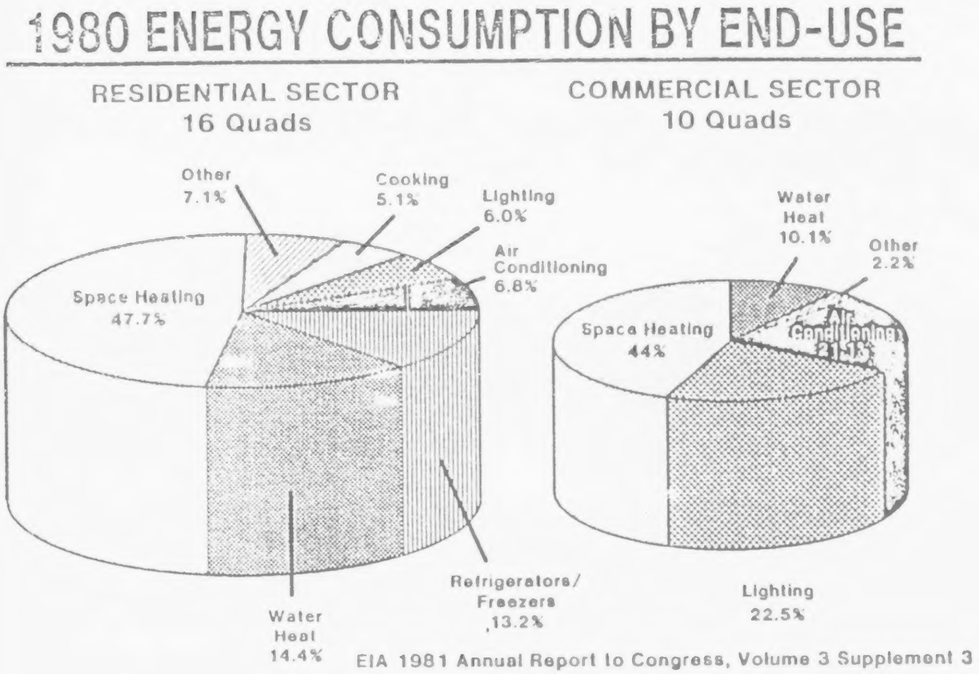
Some forecasts have been made about how energy will be used in buildings. Space heating will remain fairly high. Space cooling will become an increasing share, particu larly in commercial buildings. Lighting will go down a bit as we get some more efficient lamps and fixtures and increase use of daylighting. Water heating will remain fairly stable.

The question that comes out of the energy use in the buildings portion is: to what extent will energy costs drive change? I believe that it will be a moderate-to-major driver during this period assuming the trends I've reveiwed are not interrupted. The possibility of interruption, however, means that there's an element of unpredictability about the extent to which energy costs will influence construction.

One of the things that should be mentioned although it's a fuzzy area, is the extent to which the embedded costs of existing buildings will be a signficant factor during the next few decades. Many buildings erected when energy was not a significant cost factor will be in use for some

Figure 1

1980 ENERGY CONSUMPTION BY END-USE

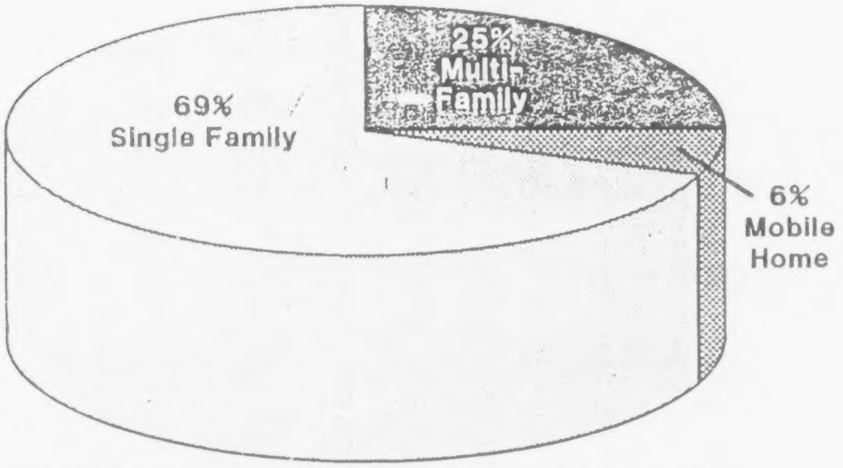


EIA 1981 Annual Report to Congress, Volume 3 Supplement 3

Figure 2

RESIDENTIAL BUILDINGS SECTOR

81 Million Occupied Units in 1980
- 69% Owners
- 31% Renters



EIA 1981 Annual Report to Congress, Volume 3, Supplement 3 time. The cost of building new structures will lend a certain economic and energy appeal to using existing buildings rather than replacing them with new ones.

I think that the relationship with electricity also will become increasingly important.

Now, I've completed my remarks about the energy use in buildings, and I'll look more specifically at how some of these affect what's taking place in the residential sector, and stray a few times into the other areas. I've followed the outline, looking at the new and emerging technologies, the way these technologies may be applied and impacts on the building construction industries. I will go through the first part of this fairly quickly and spend most of my time on the impacts.

If we look at residential or commercial buildings, we really look at three interacting systems: (1) the building envelope itself; (2) the HVAC equipment that meets the needs of the people using the building; (3) the community energy supply or utility system that supplies energy to the buildings. The efficiency that comes as the end result depends upon the relationship and the interaction among these three systems.

Now, when I talk about the technologies, I mean first, the building systems and HVAC equipment and then the community systems.

I think you might look at some of the kinds of technologies that are currently taking place as far as building systems are concerned. The kinds of things such as insulation material becoming significantly higher and possibly changing thermal resistivity. Coating that may be put on the outside of buildings may be either reflective of the energy coming in or absorbing, depending upon what is desired, and what serves the energy value of that building most effectively. Some 'smart' glazings make it possible to have two panes of glass with some material between, where electrical current may be passed through the material, causing it to be reflective or let light through, depending upon what is wanted.

I think these are areas in which work is being done on new technologies that should emerge in the near future.

We could spend a lot of time on indoor air quality. I think that area will be important, but not one I particularly want to discuss at length at this time.

I think another important area here is the retrofitting of buildings. It's harder to identify what research opportunities there are in the retrofit area. But because of what I think is the significance of retrofit of buildings, questions of engineering, optimization and selection will become increasingly important.

Also in the building equipment area, there are some very promising things going on. Thermally-activated heat pumps that have a COP of 1.7 to 2.0 should be coming into the marketplace in the 1990s. We already have heat-pump water heaters that are twice as efficient as electric-resistance water heaters. Combustion heating equipment with efficiencies over 90 percent, and advanced lighting concepts that have improvements from five percent to over 100 percent already exit. These high improvements normally involve some device for replacing an incandescent light with a flourescent light, but those technologies are available.

Integrated appliances are those which may be made into a single unit by moving thermal energy one way or another, rather than the separate major appliance units that we currently have.

Micro processors allow us to be much more sophisticated in our building control strategy. So there is a lot of technology there as well.

In the community systems area, I think the principal technologies of interest are district heating and cooling. Reducing the cost of district heating and cooling can be accomplished through lower piping costs, meters that are more accurate, heat meters, and automated combusters, five to 25 megawatts, self-contained coal-fired or petroleum-fired combusters.

This has been just a quick mention of some of the technologies, but it's representative of a sort of seething, exciting area of technological research that includes many, many more things of the kind we've discussed.

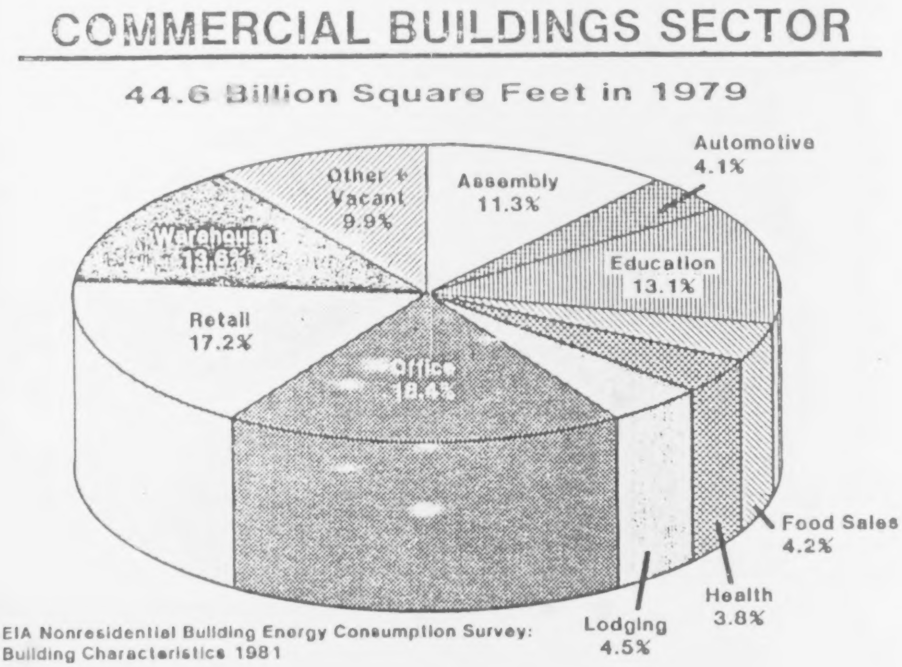
The next question is the way these technologies will be applied. One thing I think we already know, and have demonstrated fairly well, is that we now can build residential buildings that are extremely energy efficient in terms of reducing heating requirements in cold climates. That was one of the first targets at which we aimed. Single-family residences that have an energy requirement of something like one or two BTUs per square foot per degree day can be, and have been, built. These residences have a heating bill of a couple hundred dollars. We know how to do this. Less time has been spent attempting to make buildings energy efficient in hot climates where cooling is the principal concern, but we're talking about engineering applications not significantly different from those that we have used successfully in the cold- climate areas. Therefore, I think that with the application of research in this area we'll be able to solve that problem as well.

I think the significant point in many of these areas is that it's not really the absence of technological capability that is going to slow progress. I believe it's going to be more a problem of 'know-how.' Getting information about how to use the available technologies throughout the infrastructure, and also some economic constraints, may be a hinderance, but not a lack of technology.

There will be an increase in attention given to how these technologies can be applied to existing residences. The quality of construction will also be given more attention. So far a large part of the research in the residential and commercial building areas has been spent looking at how component parts of buildings work. Increasingly important, now and in the future, will be to determine the interaction of these components and how to put all of the parts together so the entire building operates efficiently.

Similar kinds of changes can occur in the building equipment area. The increased 'envelope' performance of newly-built residences will call for smaller-sized HVAC equipment. The most cost-effective retrofits in existing residences will often be done in the equipment area rather than 'envelope' retrofits.

As a result of the coupling of utility policy with building policy, more attention will be given to utility load management. Micro-processors can be used to monitor how building equipment operates in terms of its demand for electricity. Such systems will enable utilities to better match load factors with demand rates.



EIA Nonresidential Building Energy Consumption Survey: Building Characteristics 1981

Figure 3

As a result of the technologies and other things that I've mentioned, there'll be more district heating and cooling systems initiated. Not the large central systems that we've seen, but more neighborhood-sized community systems.

With regard to the impacts of technology on the building construction industries, Don Carlson's paper contains some thought-provoking points. As a result of reading his paper, I'm not as confident about some of the things I said here as I was before. Nevertheless, I will go on in an attempt to continue to stimulate some more of the lively discussion that we have had.

Continued and increased attention to energy performance in new residences, along with many other factors, will contribute to pushing up the costs of conventional, single-family residences. Concern for affordability will continue and grow. The shift to multi-family dwellings compared to single-family dwellings will continue, and a shift to smaller residences will occur. Some residences we're seeing now are really very small in size. There are condominium units of as little as 240 square feet, which is about one-sixth of what is generally considered to be the usual size.

There will be great concern for the quality of construction because of the recognition of its significance to energy performance. Tighter houses will cause increased attention to indoor air quality and other safety issues, adding potential cost for improvements. The move to manufactured, modular and prebuilt housing will continue at a moderate rate.

I come from rural Iowa, and despite the predictions of his elimination that have gone on since the turn of the century, the family farmer still hangs on there pretty tightly. I think that the home builder is much the same breed, and there will be many home builders around long after the forecasts of their demise have run their course.

There will be some increased labor shifts. This is a controversial question, and maybe we can target it. At several points here, I have talked about the impact of technology on labor and tried to predict where the impact might least affect skilled or moderately skilled labor. It seems to me that it's at least arguable that manufactured housing will lead to some reduction in the skill level required for workers.

Home builders will continue to expand into the multi-family and small commercial area. The retrofit activity will increase and provide jobs to some of those unable to find employment in new construction. The retrofit field will become more sophisticated, however, involving computer simulation of various retrofit technologies.

The heating, cooling and appliance manufacturing industries will remain active, although their product lines will change. However, if these industries fail to make the product improvements that may be called for, they will leave the door open for increased foreign competition.

The interaction between building energy conservation activities and the utilities' planning policy will become more apparent. This will lead to increased planning and management activities in terms of that interaction.

Investment in district heating and cooling systems will create construction jobs in urban areas. This is another area where I think medium and mid-level skills could be employed. These systems could be included very effectively when considering investments for renovating the urban infrastructure.

John P. Millhone is Director of the Office of Building Energy Research and Development at the United States Department of Energy

6

Construction Technologies
Richard L. Tucker

Richard L. Tucker

I'm not sure I agree with some statements made in previous papers. Rather than disagree with them, I'll just discuss the fact that there is a concerted interest and concern, particularly among the private community in this country, over the cost of construction itself. This is probably evidenced most closely by the Business Roundtable. The Business Roundtable is now right in the middle of Phase Three of a rather massive effort to look at the whole issue of growing costs in construction projects.

As you know, the Business Roundtable is made up of chief executive officers of the nation's largest corporations. They've put several million dollars of direct funding into this program, just trying to get a handle on the cost of construction and on what can be done to improve it. I would encourage you to write to them and get a copy of their reports. They have 23 separate reports that have been published. The reports are free, including a summary report entitled "More Construction for the Money."

They're now into Phase Three with an effort to try to educate the nation about all of the different factors relating to construction costs and about what should be done to improve these factors.

I have a different classification of construction than what John Eberhard presented. My classification results from a purely technological perspective. My four major categories include: residential buildings; non-residential buildings; engineered construction; and industrial construction. I would claim to you that these four categories are very distinct in terms of the types of workers that are involved in them, in terms of the types of construction companies, and in terms of the types of designers that participate in the projects.

Residential construction is dominated principally by architects, if there are any professionals at all. There are many house designers in the world that don't have any type of degree. The people that work in residential construction are relatively unskilled, compared to those that work in the other types of construction.

MR. EBERHARD: Did you say residential is dominated by architects?

MR. TUCKER: I say if there are any professionals, it's dominated by architects. It's really dominated by the people that push and develop them as far as the technical aspects of it are concerned.

Now, I'm not talking about the land development, John, I'm talking from the standpoint of the structural design, the components that go into it. All of this is a technical classification rather than a marketing classification.

Non-residental buildings are certainly dominated by architects. The engineering component in buildings is relatively small compared to the architectural component.

The engineered construction probably should be classified as civil engineered construction. That is, it is dominated by the civil engineering community: highways, dams, bridges, those kinds of things.

Industrial construction is dominated by other types of engineers: chemical, mechanical and electrical engineers. These projects include power plants, process plants, and other similar areas.

The size of the industry is one of the problems that we have. We don't know how to measure the size. Figure 1 came out of the Business Roundtable study in which they tried to compare the Census Bureau's numbers and their own estimates. On the left, it shows the total industry in the United States comprised $229 billion for 1979. The Business Roundtable went back and took data that they had from their own companies and showed some rather major changes in it and put the size at a round number of $300 billion a year.

This also shows, if you believe these numbers on the right, the relative magnitude of the different components of the industry, and it shows perhaps a different set of numbers than what John gave us yesterday in his presentation. Any way you look at it, the industry is very large and the opportunities for change are significant.

Similar data from the Roundtable show the construction cost index and that it is, at best, subject to dispute. It's part of the problem we have; we can't measure anything we agree on. Nonetheless, the construction cost index, as you look at numbers from back at 1967, shows that over the past fifteen years or so construction costs have gone up approximately 50 percent more than the rate of inflation as a whole for the nation.

The productivity index is just as controversial. I could show a variety of statistics. They all show the same kinds of trends, and that is that over the past fifteen or twenty years or so, construction productivity has dropped, again about 50 percent, compared to the rest of the economy.

Now, the Roundtable is very concerned about this. In contrast to some of the things that we were discussing yesterday, what these companies are saying is they're only going to put a certain amount of money into construction, and unless the productivity goes up, they're not going to build as much. Indeed, the nation's larger companies have quit building as much as they have. It's a crisis as far as they're concerned.

One of the unique characteristics of construction is that it's very heavily dependent upon job site labor, and productivity almost translates to the productivity of the craftman's time. You're not going to find the numbers in Figure 2 in the literature because I made them up.

(Laughter.)

MR. TUCKER: But I made them up with a certain amount of background, and you can find a lot of numbers in the literature that are compatible with these. I've shown these figures all over the world and to many of the companies in the United States, and what they tell me is that if anything the top number, showing 40 percent productive labor time, is a little bit high, and they feel that perhaps it realistically should be lower than that.

That doesn't mean that craftsmen aren't busy more than 40 percent of the time. It means that their time is not necessarily spent productively.

Figure 1

TYPICAL CONSTRUCTION WORKER TIME

PRODUCTIVE	40%
UNPRODUCTIVE	
Personal	5%
Jurisdictional	15%
Poor Methods	20%
Administrative Delays	20%

Figure 2

U.S. CONSTRUCTION INDUSTRY SIZE

	1979 Government Figures (billions)	Study Team Estimate (1979) (billions)
Industrial	$ 14.95	$ 69.0
Office Buildings	9.46	14.2
Commercial Buildings	15.46	23.2
Other Private Business	2.99	4.5
Farm and Private Institutional	11.59	14.6
Public Utilities	26.47	26.5
Residential	99.03	99.0
Government	49.00	49.0
TOTAL NEW CONSTRUCTION	$228.95	$300.0

However, we have a lot of work sampling studies and other data that show — I guess the particular extreme is the nuclear power plants — that 30 percent is about all of the time that they're busy at all on some projects.

If you look at the sources of the other 60 percent of craftsman time, then some of it perhaps is personal. I put five percent down there. Some people might claim that it's higher. Ten percent is about as high as you can find anyone that would realistically claim that it is on the average.

Jurisdictional problems may be due to unions, but not necessarily so. Even the merit shop companies have a kind of artificial jurisdiction that they've established where one craft does one thing and one craft another thing. Carpenters don't put in conduit, for example, even though they're quite capable of putting in conduit. There are lots of jurisdictional problems. Operators can't unload the truck. It takes a particular craft that has the stuff on the truck to unload their stuff. Perhaps that's some wastage of time.

Perhaps the ones that we should focus on are mostly the bottom two, the poor methods and the administrative delays. The methods themselves are the things that relate specifically to technology and the technology of putting the work into place, that of physically making the attachments.

Administrative delays relate pretty closely to the computer issues that Harry was talking about yesterday. These projects have many parties participating in them, and the communications are very tough. I could show you some other figures that would show you magnitude, but I won't because of time.

If we want to see the opportunities for improvement from a technological standpoint, then we probably should look at the different areas of a project as they take place. These are shown in Figure 3, as well as indicators of inefficiency.

Then if you look at the sources of inefficiency, and the things that might be indicators of inefficiency, how difficult is it to estimate costs for an area, how sensitive is that area to design, what's the lead time for schedule in the area, how much rework takes place, and so forth, then you can begin to get some kind of a feel for it. The numbers in Figures 4-7 represent the opportunities for technological improvement. The manner in which we developed quantitative numbers was to survey rather knowledgeable people in some of the nation's largest companies and ask them to rate these on a scale of one to ten. The number one meant that it was very easy to do something, a ten meant that there was a lot of difficulty and had a lot of inefficiency associated with it.

Then we took those average ratings and multiplied them by the percentage costs of a total project and broke them into four sectors. The power sector is one, and if you look at that sector (Figure 7), then it's obvious that the length of the bar, which is a combination of the relative cost impact and the difficulty on a project, it falls into the piping and mechanical equipment installation and electrical category.

Heavy industrial projects (Figure 6), such as process plants and steel mills, show the same major areas: piping, mechanical equipment, installation, electrical. Piping shows up much more dominantly. As a matter of fact, piping is not only the largest portion of those projects, but also the most inefficient element of those projects, and so the length of that bar is rather obvious.

Now, remember this is a $60 billion per year industry. So it's not something to sneeze at. It is comparable to the size of the housing industry.

Light industrial plants are more building oriented, and as a result, the things that relate to buildings and some other things begin to become prominent. The structure, for example, begins to be a prominent area in light industrial buildings.

Then the structure, the enclosure skin and the interior finishes, are all very prominent, and as you can see, electrical is relatively more important in buildings than you would think. From the presentations we heard yesterday, electrical is going to be increasingly important in buildings.

Well, these are where we should probably be putting our attention. If you look at the areas of highest technology potential, then in buildings it falls into the structure, enclosure skin, interior finishes and electrical; in the other sectors, into these other three areas.

Even in buildings, I might advise you that plumbing, piping, those things are not insignificant. They're areas that justify attention.

If you look at an industry-wide basis and try to focus on the areas that have the greatest potential for this $300 billion a year industry, strictly from a technological improvement opportunity, then the piping, mechanical equipment, installation, electrical are the highest areas of potential. This is a weighted scale. The high areas of potential involve the structure and setting of vessels in the HVAC systems, installing special equipment and instrumentation, and are not incompatible with the things that we heard yesterday.

Some areas have lower potential. We complain a lot about roofing in buildings, and it certainly has an impact from a long-range operation standpoint. It has very little impact from the standpoint of efficiency of installing the project itself. The same thing is true with insulation and painting. Those are relatively

Figure 3

	CIVIL					MECHANICAL						OTHERS					
	Earthwork	Foundations	Structure	Enclosure Skin	Interior Finishes	Roofing	Piping	Plumbing	Vessels	HVAC	Mechanical Equipment	Special Equip. Installation	Electrical	Instrumentation	Insulation	Coatings and Painting	Fireproofing/Protection
a. DIFFICULTY IN ESTIMATING COSTS																	
b. SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN																	
c. NECESSARY LEAD TIME FOR SCHEDULING																	
d. PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT—NOT DESIGN)																	
e. UNPLANNED REWORK ON YOUR TYPICAL PROJECTS																	
f. WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS																	
g. PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION																	
h. SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY																	
i. NUMBER OF DIFFERENT CRAFTS REQUIRED																	
j. DEPENDENCE ON FOREMEN COMPETENCE																	
k. CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION																	
l. REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION																	
m. NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)																	
n. MOST WASTED TIME AMONG CRAFTSMEN																	
o. WASTED TIME WAITING FOR INSPECTIONS																	

small portions of projects, and they're relatively efficient compared to the other aspects of the projects.

We went through some number systems and tried to take just those three areas of highest potential and estimate the savings on a nationwide basis per year, if you could just make those three areas no more inefficient than the average of the rest as a whole. So this isn't the potential that we could improve those, but just bringing them down to the same level of inefficiency as everything else, and as you can see in Figure 8, the potential savings are significant.

If you're wondering what the average cost of these projects is, this is based on a $25 million building because that was what was reported by the companies, and it shows an average savings of $91,000, even though those three areas aren't the highest potentials for buildings.

Incidentally, the structure is only an area of potential because of its relative magnitude in the project. It's a relatively efficient area of a project compared to the other areas of a building project.

I think the average cost of light industrial projects was about $120 million, and the heavy industrial, about $200 million, and power plants, about $500 million. On a nationwide basis for the gross industry then, the figures show that we could save about two billion dollars a year by just improving those three areas, not to say the other areas that are of higher potential in buildings.

Then you can go back and look at the activities that go into each of these areas. We picked six of these areas: electrical, instrumentation, piping, equipment installation, and then we broke the structure into two areas because concrete and steel construction have distinctly different characteristics.

We've investigated them pretty carefully. (Figures 9-14). We took the activities involved in steel construction, for example, setting the columns, setting the beams, making the connections as shown in Figure 14. The temporary connections and the final connections, putting in shims and cleaning the anchor bolts seem to be the major things in steel construction. We determined how much time each of these takes. Setting the column takes about 35 percent of the time in the cycle; setting the beams, 25 percent; final connections, 20 percent; temporary connections, 15 percent. I wouldn't claim to want to bet a lot of money on the accuracy of these numbers, but they're as good as I've seen.

Then we asked the people in the field, the superintendents in charge of these operations, to rate each of these areas on the basis of how complicated it is, the complexity of that particular activity, how much skill, the level of skill required for that activity, and then the dependence on accurate technical information for that activity because of this interface between design and construction that takes place, and that's what the ratings here indicate.

Invariably, what we find is that the ones that take the most time are also the ones that rate highest on all three of these areas. So it's possible to determine which kinds of activities tend to lend themselves to this inefficiency. It is somewhat subjective, but about as quantitative as we can make it at this stage.

Figure 13 is for concrete; constructing the form, setting the reinforcement, locating the forms, placing the concrete, aligning the forms, removing the forms after you've got the concrete placed, and so forth.

From this we focused on six activities and examined technological improvements that would lend themselves to major changes.

What we find in concrete work is that the designers, the structural engineers, architects, and so forth, tend to design the concrete structure as it's going to be in the final building. They don't tend to put much detail in design on how it gets in place. They will show where the reinforcement is located. They don't say anything about imbeds. Architects love to put a lot of imbeds in places for electrical boxes and those sorts of things, and those just play havoc with the construction crews because those imbeds somehow are supposed to be there when it's finished, but they're not designed on how they're attached to the forms while you place the concrete in them. When you put some kind of electrical box into the concrete form, and you depend on the workers in the field to somehow hold it in exact position while you place the concrete around it and push it around, it causes a lot of difficulties.

The lack of communication between designers and the people physically constructing these things causes lots of problems. Well, in the cost of concrete structures, the cost of the concrete form work itself is roughly equivalent to the cost of the concrete, the cost of the concrete and the steel. The cost of just the form work is roughly half the total cost, and it's the most volatile thing. If you talk to a construction company, they'll always tell you that they could care less about how much concrete it takes because they can figure that up pretty good, but they put all of their attention on figuring out how to design the form work and how to reuse the forms.

If you look at all of the other elements of construction, whether it's electrical, instrumentation, equipment setting or anything else, you'll find that the common thing is making connections: that is the common problem that wastes all of the time in the construction industry: making any kind of connection, whether it's a beam to a column, a beam to a beam, electrical wire that you're putting terminations in, whatever. The connections are the things that have the very high level of inefficiency. We haven't yet learned how to do that with robotics or any other kinds of machines. It still takes people and is a very inefficient operation, a lot of standing around all the time they're doing it.

Now, I want to talk about the breakdown between design and construction. I spent a lot of time studying a large precast erection project a few years ago in Houston. It had about 2,500 beams and columns and double-Ts that had to be put in place. We were studying the efficiency of the erection operation rather carefully. The vertical scale on Figure 15 is the number of pieces that were erected each day. The horizontal scale is time. As you can see, the

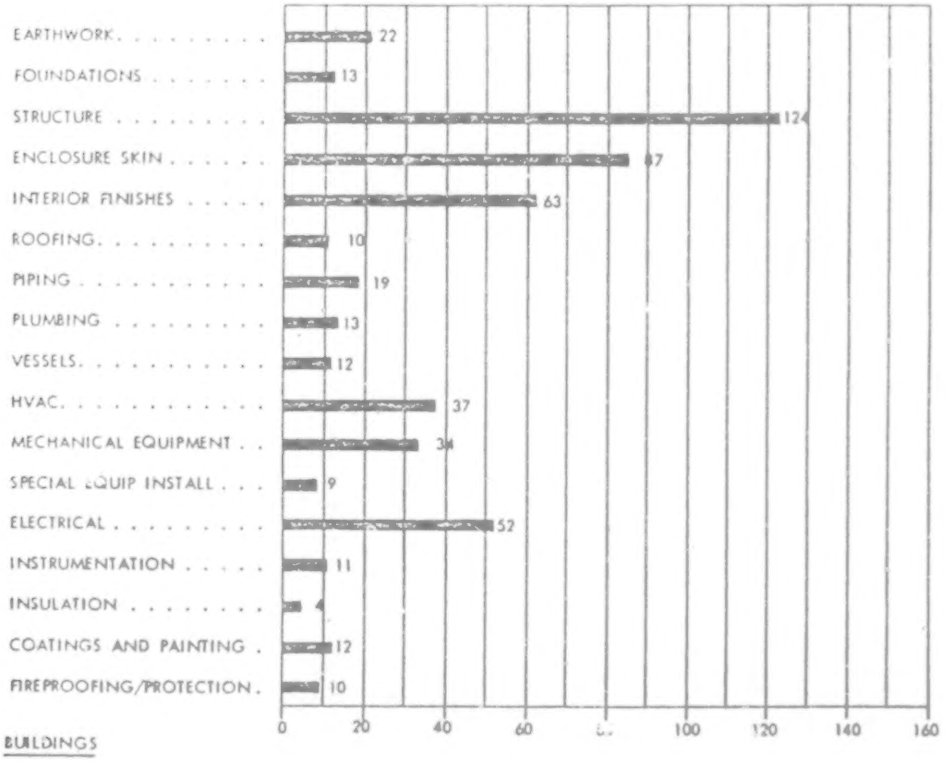


Figure 4

pieces/day varies all over the place. The factors that cost time are fit-up problems.

Figure 16 illustrates that if you put a double-T on a ledger beam that you have some tolerance. One inch is typical. We took several structures and compared them. The one-inch tolerance that these were designed for resulted in a five-inch bearing area plus or minus a half inch. You can see the range shown in about seven thousand measurements. What this says is that we need to integrate the design, definition, construction sequence much more and have a lot more interaction between the designers and the others. This is the potential impact of that integration. I've also put this on the handout.

In terms of combined impact of all of these things, I suggest to you that we're going to see some rather major changes. I'm claiming that technological changes are going to be made in the construction aspect of the industry, regardless of whether there's a Government program or not. The climate is here. We're going to have to have more integration of the design and construction. We're even going to get the owners into these things. We're going to find more machine-driven construction processes instead of people-driven construction processes, and we're going to find some major revisions in contract strategies. Instead of completing a design and putting the thing out for competitive bids, we're going to have to get the contractors in on it at an earlier stage. We'll have to have contracts that will speak to that point.

Richard L. Tucker is Director of the Construction Industry Institute at the College of Engineering, University of Texas at Austin.

Figure 5

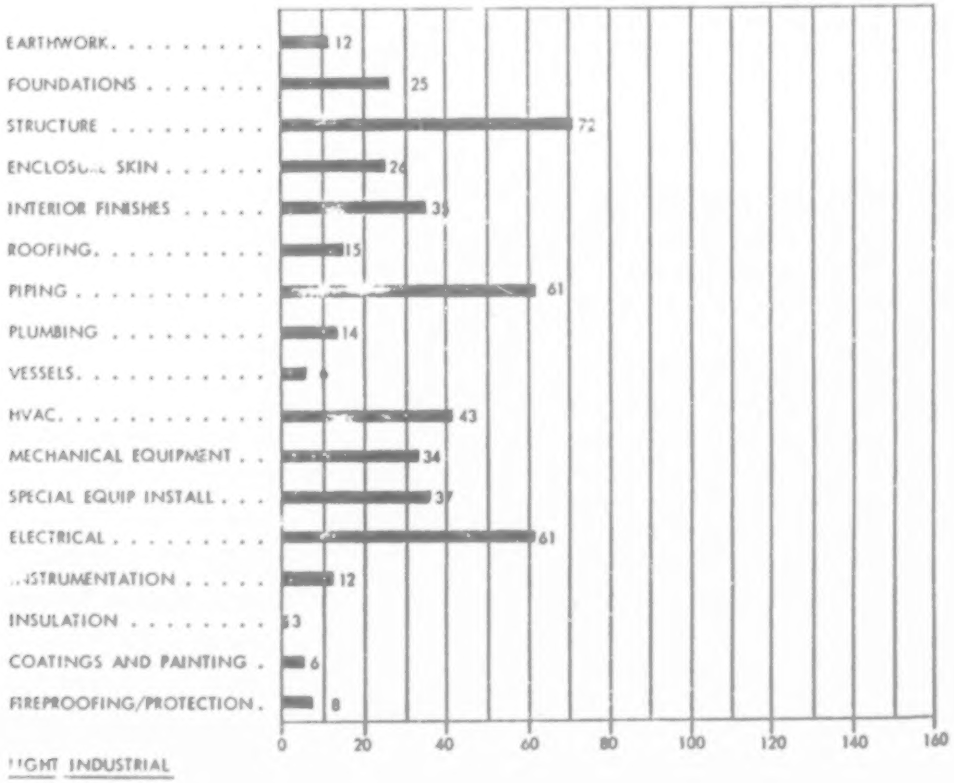


Figure 6

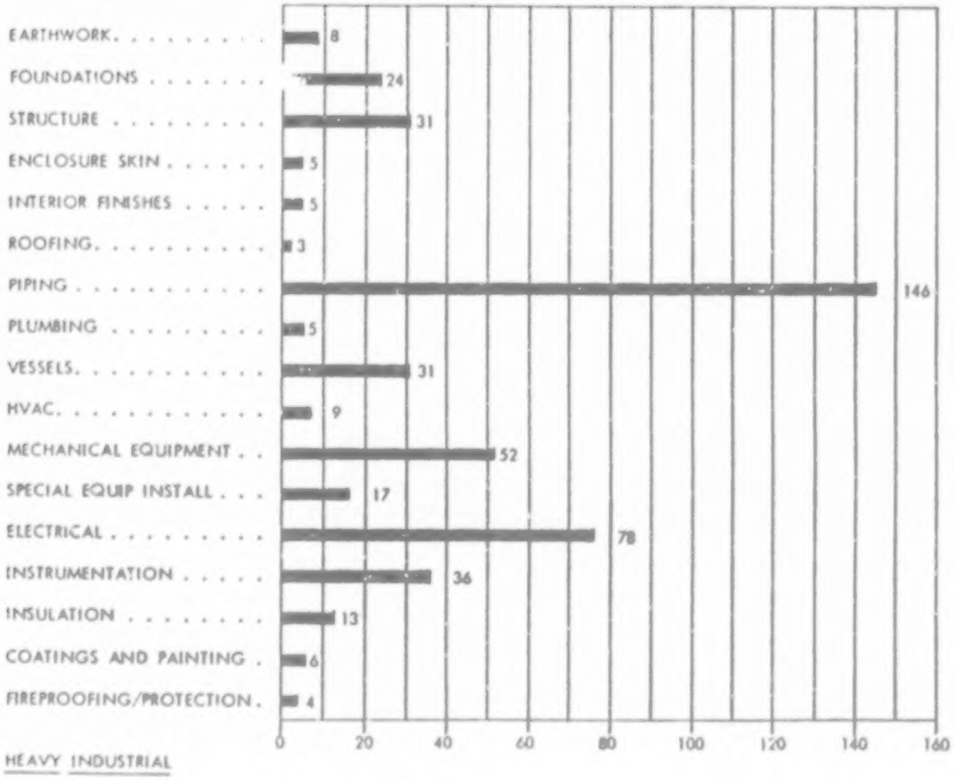
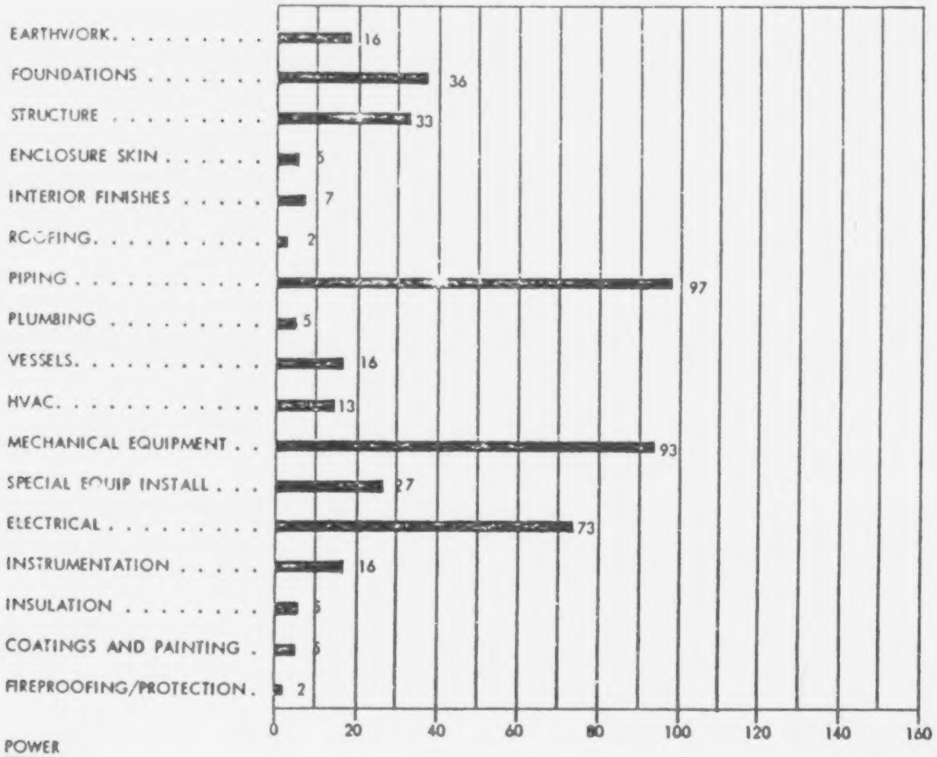

EARTHWORK 8
FOUNDATIONS 24
STRUCTURE 31
ENCLOSURE SKIN 5
INTERIOR FINISHES 5
ROOFING 3
PIPING 146
PLUMBING 5
VESSELS 31
HVAC 9
MECHANICAL EQUIPMENT 52
SPECIAL EQUIP INSTALL 17
ELECTRICAL 78
INSTRUMENTATION 36
INSULATION 13
COATINGS AND PAINTING 6
FIREPROOFING/PROTECTION 4
0
20
40
60
80
100
120
140
160
HEAVY INDUSTRIAL

Figure 7



POWER

Figure 8

Individual Project Basis ($ millions)	Piping	Mechanical Equipment	Electrical	Total
Buildings (25 million)	.006	.039	.046	$ .091 million
Light Industrial ($120 million)	.241	.174	.258	$ 0.673 million
Heavy Industrial ($190 million)	3.802	1.002	1.410	$ 6.214 million
Power ($470 million)	5.060	3.046	2.744	$10.850 million
Gross Industry Basis ($ billions)				
Buildings ($69 billion)	.017	.108	.128	$ .253 billion
Light Industrial ($33 billion)	.067	.048	.071	$ .186 billion
Heavy Industrial ($33 billion)	.667	.176	.247	$ 1.090 billion
Power ($27 billion)	.292	.176	.158	$ .626 billion
Total ($162 billion)	1.043	.508	.604	$ 2.155 billion

*Assumptions

1. Labor component is 25% of a project.
2. Improvement would allow Piping, Mechanical Equipment and Electrical to achieve _average_ indicator ratings.
3. Numbers in parentheses are total project costs.

Figure 9

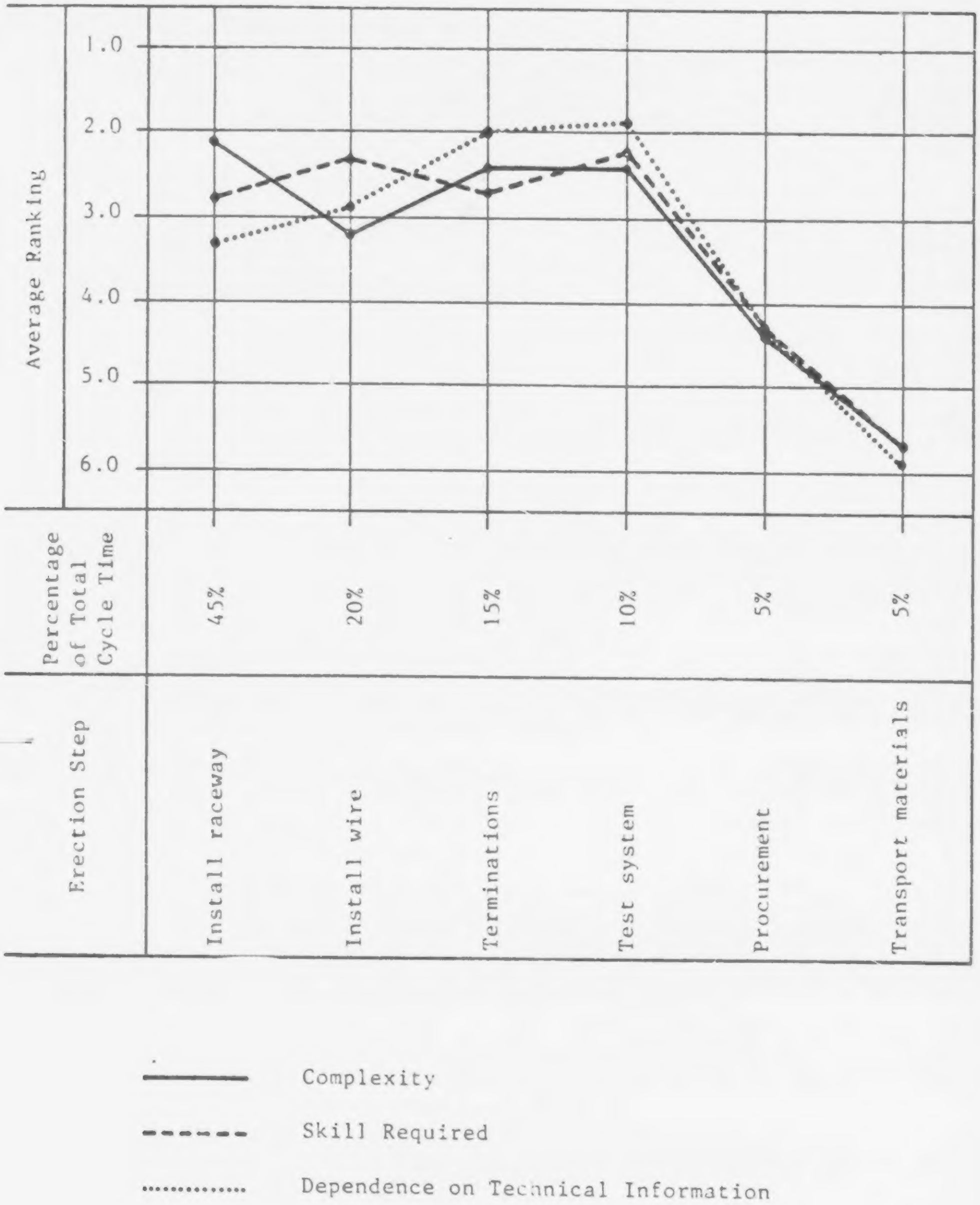
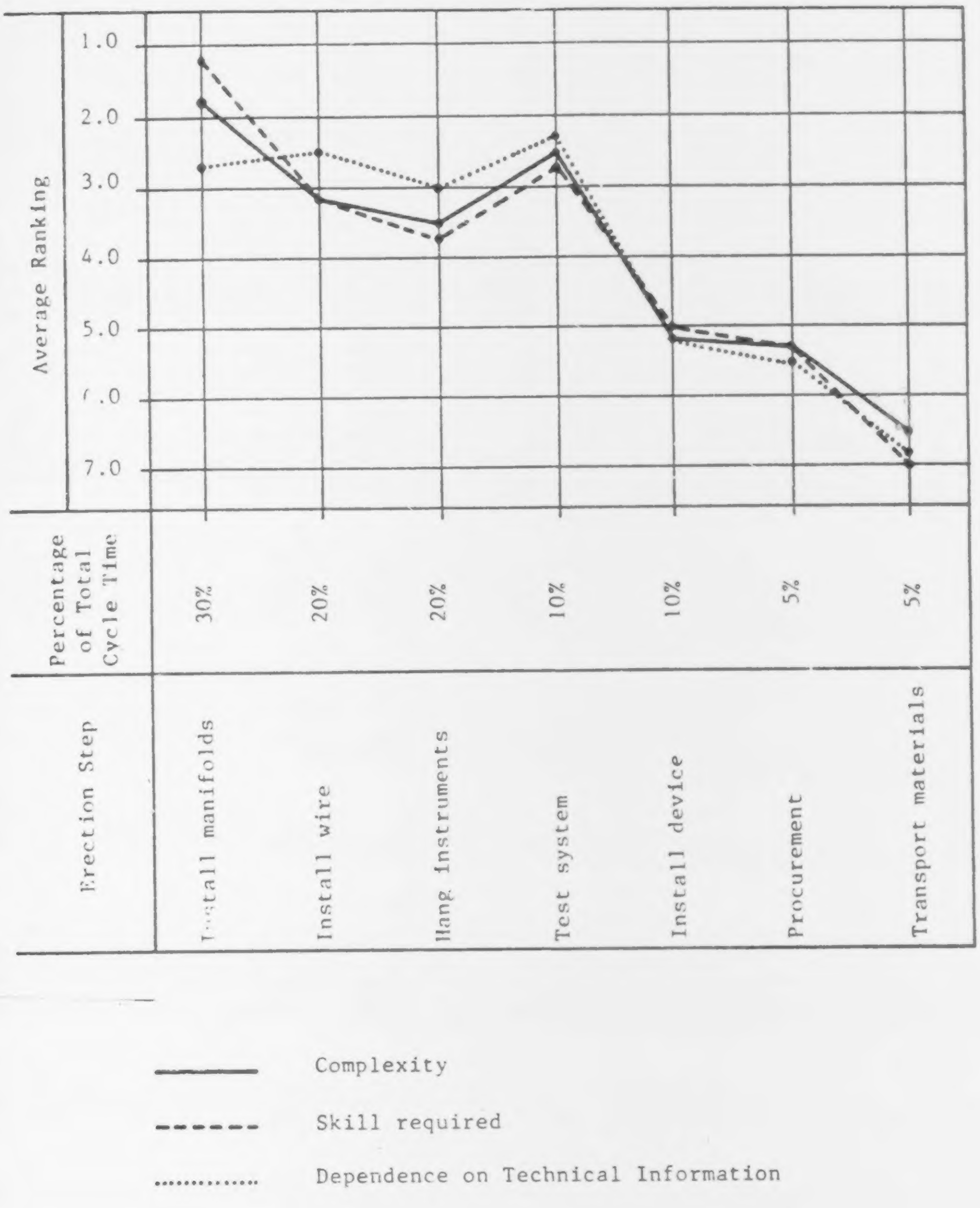

Average Ranking
1.0
2.0
3.0
4.0
5.0
6.0
Percentage of Total Cycle Time
45%
20%
15%
10%
5%
5%
Erection Step
Install raceway
Install wire
Terminations
Test system
Procurement
Transport materials
Complexity
Skill Required
Dependence on Technical Information

Figure 10


Average Ranking
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2.0
3.0
4.0
5.0
6.0
7.0
Percentage of Total Cycle Time
30%
20%
20%
10%
10%
5%
5%
Erection Step
Install manifolds
Install wire
Hang instruments
Test system
Install device
Procurement
Transport materials
Complexity
Skill required
Dependence on Technical Information

Figure 11

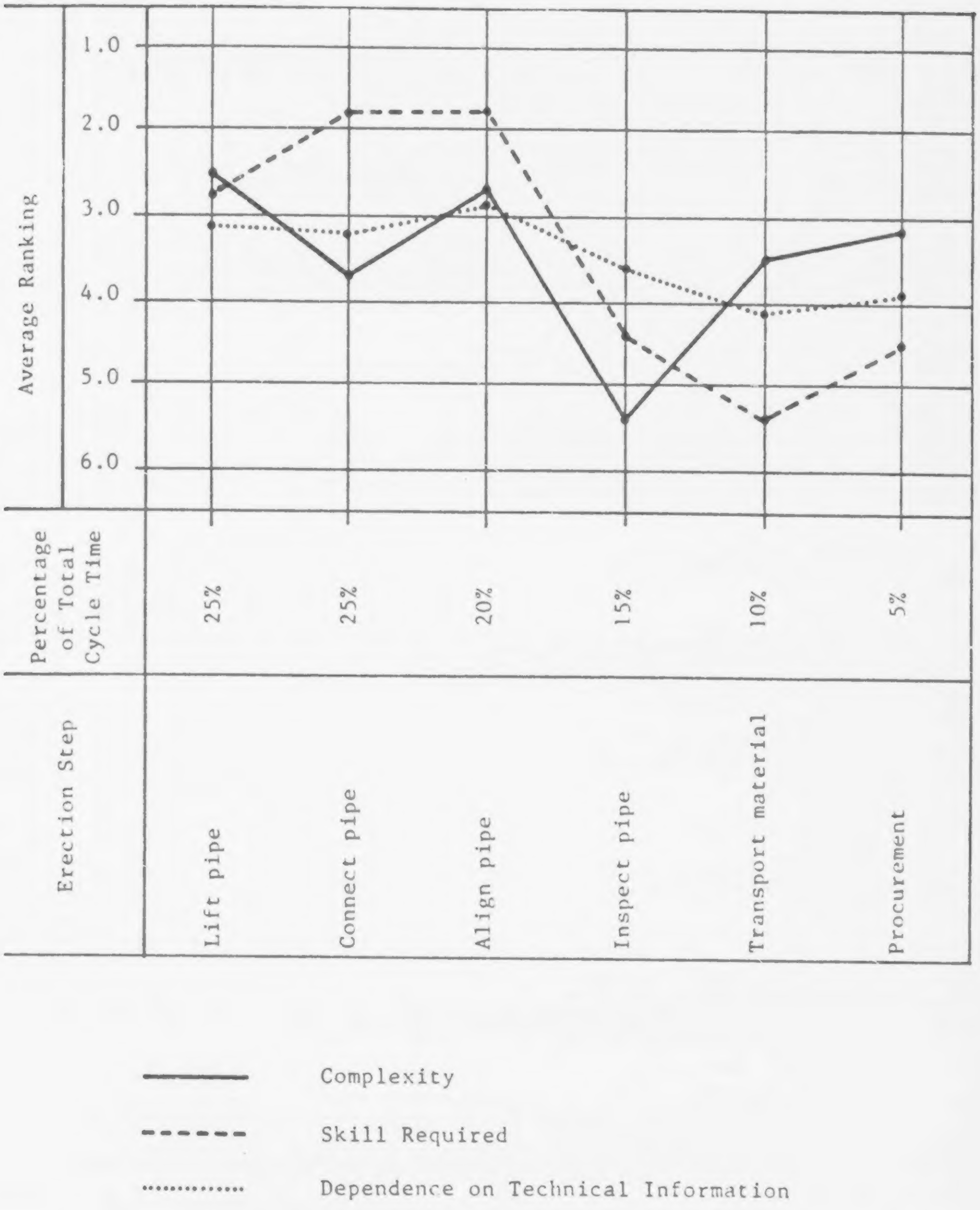
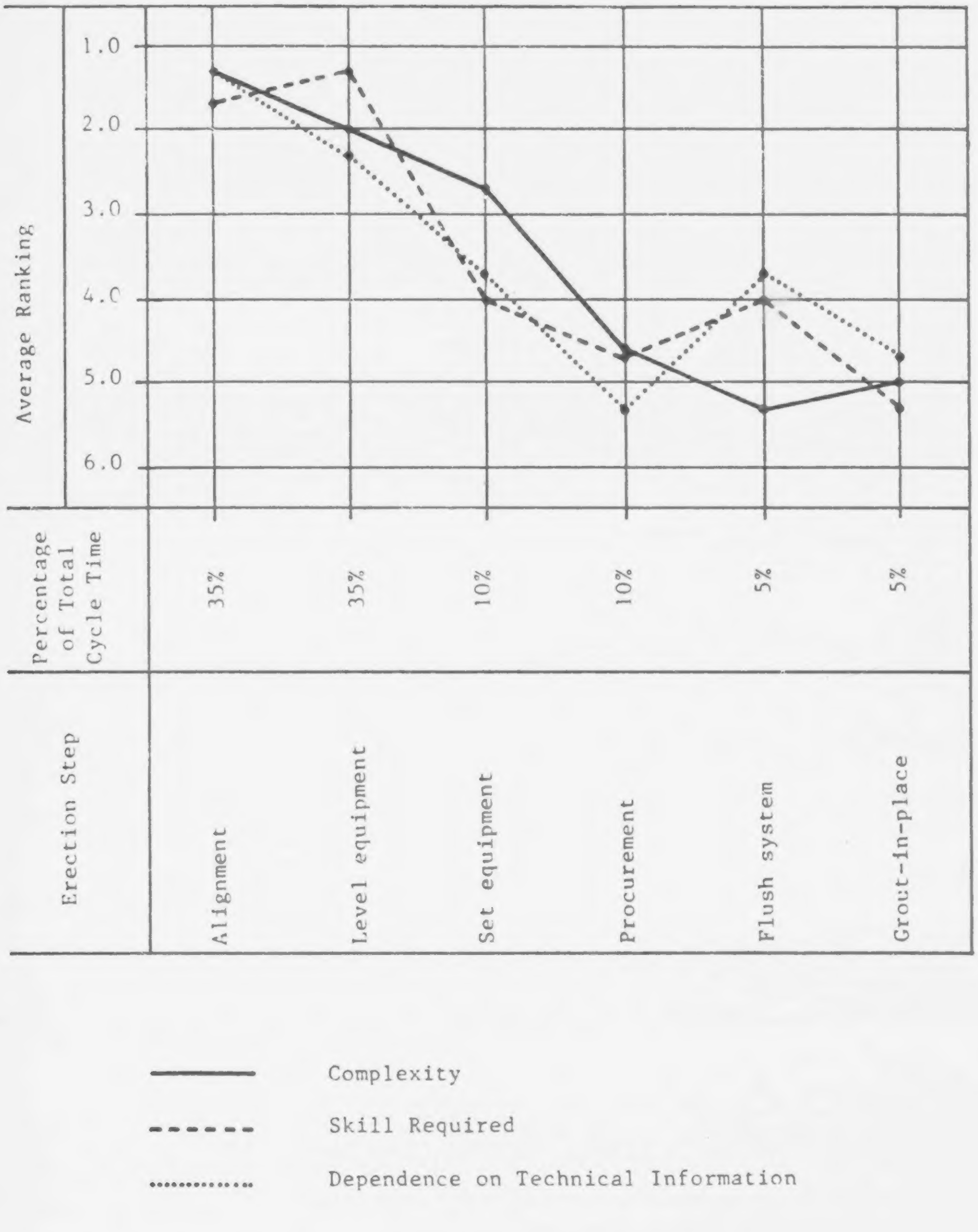

Average Ranking
1.0
2.0
3.0
4.0
5.0
6.0
Percentage of Total Cycle Time
25%
25%
20%
15%
10%
5%
Erection Step
Lift pipe
Connect pipe
Align pipe
Inspect pipe
Transport material
Procurement
Complexity
Skill Required
Dependence on Technical Information

Figure 12


Average Ranking
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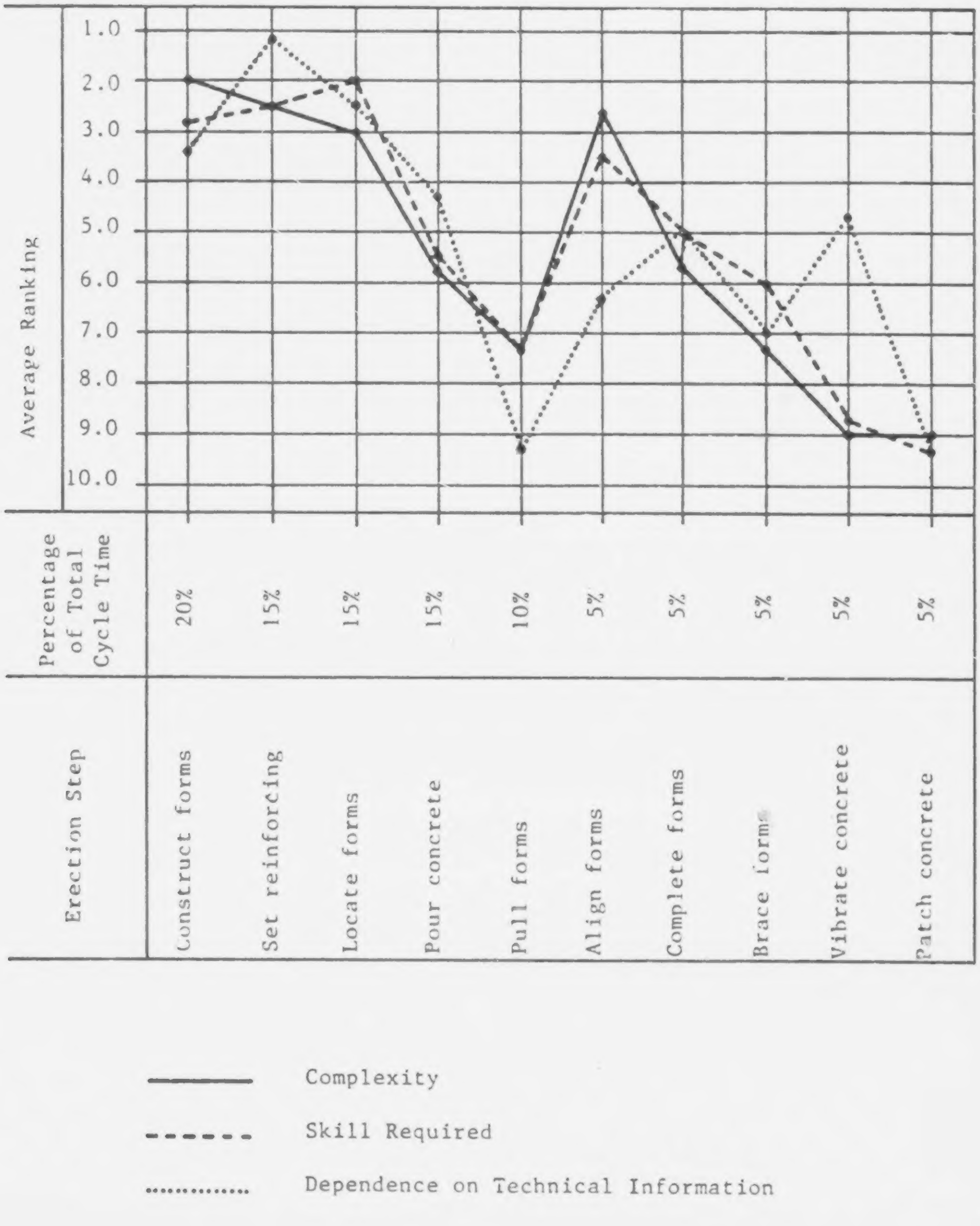
2.0
3.0
4.0
5.0
6.0
Percentage of Total Cycle Time
35%
35%
10%
10%
5%
5%
Erection Step
Alignment
Level equipment
Set equipment
Procurement
Flush system
Grout-in-place
Complexity
Skill Required
Dependence on Technical Information

Figure 13


Average Ranking
1.0
2.0
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5.0
6.0
7.0
8.0
9.0
10.0
Percentage of Total Cycle Time
20%
15%
15%
15%
10%
5%
5%
5%
5%
5%
Erection Step
Construct forms
Set reinforcing
Locate forms
Pour concrete
Pull forms
Align forms
Complete forms
Brace forms
Vibrate concrete
Patch concrete
Complexity
Skill Required
Dependence on Technical Information

Figure 14

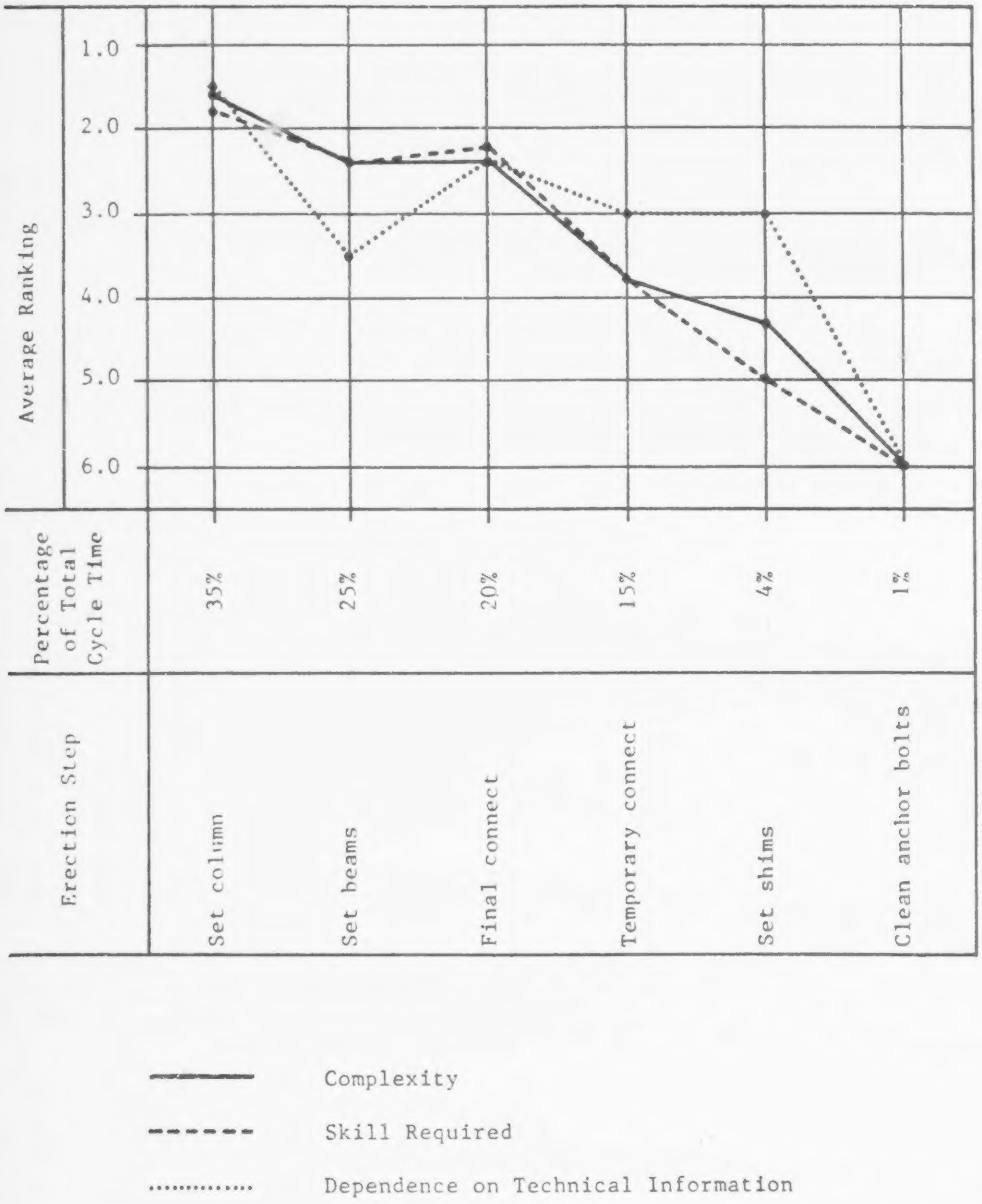

Average Ranking
1.0
2.0
3.0
4.0
5.0
6.0
Percentage of Total Cycle Time
35%
25%
20%
15%
4%
1%
Erection Step
Set column
Set beams
Final connect
Temporary connect
Set shims
Clean anchor bolts
Complexity
Skill Required
Dependence on Technical Information

Figure 15

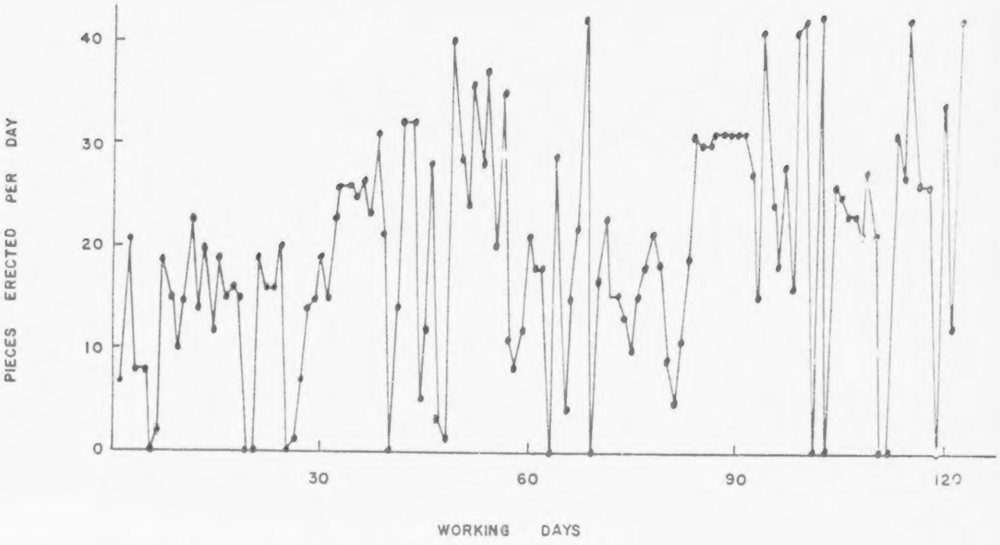


Figure 16

Bearing length in inches (1)	Frequency for Parking Garages				
	NS (2)	SS (3)	DP (4)	BH (5)	CB (6)
2 - 2/4		2			
2 - 3/4	2	1			
3	13	9			
3 - 1/4	26	15	1		
3 - 2/4	64	39	1		
3 - 3/4	109	64	5	1	
4	162	180	6	1	6
4 - 1/4	217	240	13	6	15
4 - 2/4	240	301	16	9	49
4 - 3/4	256	368	45	26	89
5	266	324	59	66	166
5 - 1/4	208	248	108	110	187
5 - 2/4	135	147	128	200	175
5 - 3/4	82	73	182	314	89
6	28	41	180	335	35
6 - 1/4			191	294	2
6 - 2/4			174	144	
6 - 3/4			128	66	
7			96	15	
7 - 1/4			42		
7 - 2/4			6		
Total	1,808	2,052	1,381	1,587	813

Note: 1 in. = 25.4 mm

7

Structural Systems
Wendel R. Wendel

Wendel R. Wendel

I'm going to talk about what we've been doing at Space Structures in the hardware area as well as the software area.

By hardware I mean the physical nuts and bolts, and by software I mean the computer-aided techniques that we build at Space Structures.

Secondarily, I want to talk about the development of a new organizational position of Space Structures in the industry as a systems specialist. I want to cover eight concepts.

One is the standardization of design/fabrication process. We want to get away from the idea that you're going to standardize a component and you're going to mass produce those widgets and send them out the door, and that's going to save building technology. That's a mistaken idea. It will always be wrong. It will never apply. The idea is that you standardize the *process* of how something's built.

Secondly, I want to talk about new forms and shapes. We basically have a box mentality. All of the buildings we are sitting in right now are box shape. There are a lot of other forms and shapes which may be much more appropriate in many different applications. We really are just beginning to touch upon those possibilities.

Third, I want to talk about the use of lightweight building materials. Our specialty is working with aluminum, working with membrane materials, working in plastics and glass. Light weight materials open up the marketplace. Space Structures is based in New York but we have offices throughout the world. We're not just a New York firm or a regional firm, but a world firm.

I want to talk about the three Rs of buildings. I've almost never or rarely talked about this, but we have a bunch of people out there designing buildings which are basically monuments. We really should start looking about the three basic Rs, which means relocatability, readaptability, recyclability of the building.

The fifth one we want to talk about is the restructuring of the labor which goes into building with new building technology. In our own experience, we find 90 percent of the work done is in the shop, only ten percent in the field. We never build anything in the field. We only assemble it in the field. We fabricate in our plants.

I also want to talk about the new market out there which extends the building technology. I know we are having our guest here from NASA talking about NASA technology coming back to the building industry. I actually think we can get more than the technology from NASA, and I want to talk about what our programs have been in those areas. The marketplace is not just terrestrial. You've got to think on a global, galactic scale. Eventually, we want to change the name of the corporation from Space Structures International Corporation. Our plans are once we get something in space, we want to change it to Space Structures Intergalactic Corporation.

We also want to talk about quality, quality in the sense that buildings should be structural art. We somehow get the idea that we're finding cheaper and cheaper ways to put up buildings, and that's really what the needs are. But that is not the real cost of buildings. We could really build most buildings as pup tents, and basically protect ourselves from the environment, from the rain, the weather conditions and things like that. A lot of the cost of buildings is it's social status indicator, the costs which go into a building, and if we're doing that, we should at least spend the money in the planning to create better looking buildings.

Most buildings I find are really trashy, industrial designs. I think there's a lot more which can be done, especially if we use technology in those areas, and I think we can be much more creative.

And the last item is the development of the new teams. As a systems specialist in the industry, I see the industry greatly changing. I've found in my thirteen years in building my company we've seen a change in that amount of time. We'll talk at the end about where those changes come about and how the new teams are being put together.

As I said, Space Structures' philosophy is 'where visions take shape,' and we're going to talk about space networks, new forms, new shapes and new systems, and we'll talk about the second generation of space frames. In the products that we do, we do space frames which we call Octa Hubs and Orba Hubs, two different systems, and the new designs tool is called SSCAD, Space Structures Computer Aided Design.

Back in 1980, I invented two new space frame systems. The red one in my hand (see Figure 1) is called Octa Hub. The one in my left hand, the golden, brass colored one is called the Orba Hub system. They were invented about six weeks apart from each other. Both are patented systems, and basically it's the result of about ten years of work in doing different types of structures, mainly specializing in domes.

We decided to get into the space frame area after I had sold two contracts, one for a big atrium and skylight on the Hyatt Hotel in Crystal City, Va. and one for three sports enclosures for Aramco.

Figures 2 and 3 show the Octa Hub system, which I invented in 1980. Our basic material is aluminum here. It's an extrusion bolted together with square tubing where the tubing can take various wall thicknesses. We're using pins rather than bolts to put it together to reduce down the amount of on-site installation time. With an Octa Hub system, we typically might be doing a million dollar job and charging only $50,000 for the installation.

Figures 4 and 5 show details of the Orba Hub system. It is a solid aluminum ball. Tapered ends, struts, and multiple types of finishes can be put on the system.

A space frame can be a very simple structure. Figure 6 shows a flat structure that most people expect when they think of space frames. Here in the United States we expect space frames to be little atriums or canopies. But space frames can take many forms. Figure 7 shows the Federal Express Pavilian at the

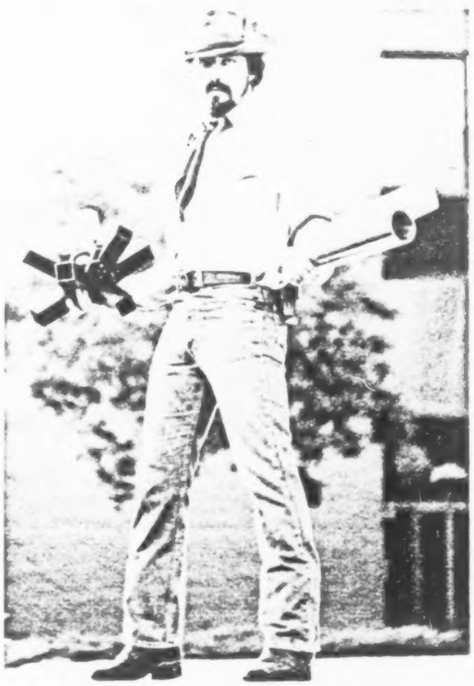


Figure 1

Figure 2

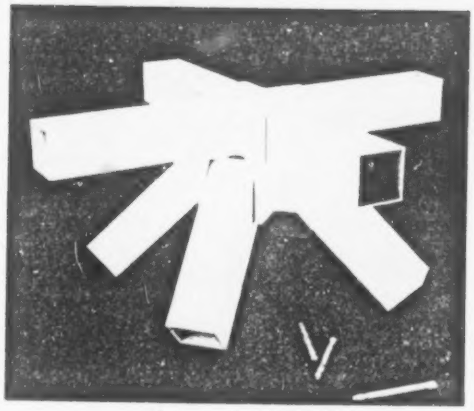
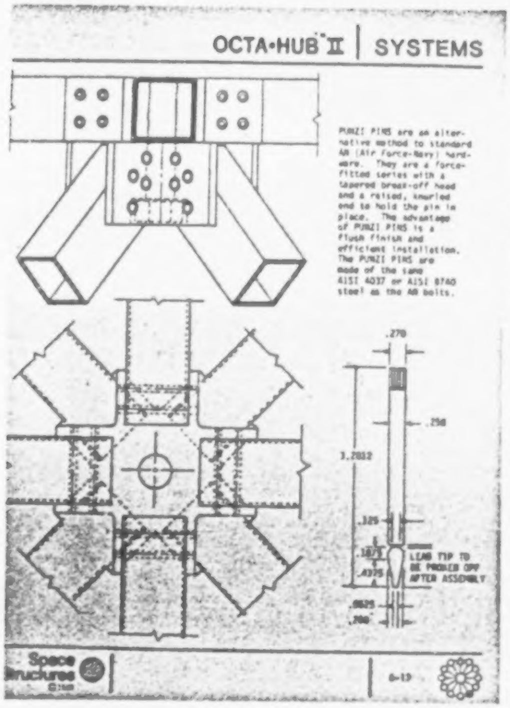


Figure 3



PUNZI PINS are an alternative method to standard AN (Air Force-Navy) hardware. They are a force-fitted series with a tapered break-off head and a raised, knurled end to hold the pin in place. The advantage of PUNZI PINS is a flush finish and efficient installation. The PUNZI PINS are made of the same AISI 4037 or AISI 8740 steel as the AN bolts.

World's Fair down in Knoxville I did for Federal Express back in 1982. It's a multiplate type of design. The whole building is a space frame, as is the laser tower.

I now want to talk about SSCAD, which is one of the main tools and the assets of space structures. We started writing our own program back in 1973. At that time we were buying computer time from Boeing and McDonnell Douglas. About three and a half years ago, we bought our first computer, and we started further development of SSCAD to give us a total knowledge system.

One of the things we've seen in some of the talks yesterday about design, we've almost talked about computer systems basically replacing the pencil. Well, at Space Structures, the computer systems replaced the pencils and eventually we go up and we'll take everybody's pencil away from them. We're going to gold plate it, put it up on the wall and say, "The last day a pencil was ever used at Space Structures." We want to eventually get there.

But what we want to say is also the computer systems can extend the design process. The idea of computers replacing what's being drafted right now is fine, but that's not the real impact. The real impact is when we change the design process, change the possibilities, change the potential.

SSCAD is a computer system designed in about ten main sections. Each amount of the pie on Figure 8 indicates about its magnitude. We use the system from the proposal stages through design, through loading, which means loading up the structure for analysis, and we run our analysis, our finite element anaylsis, on it. We use it for post-analysis processing. We generate all drawings from it. It's used in planning out the fabrication, material management. It's used to plan out the installation of the rigging, which is used to lift the structure, and it's used to store historical data.

We found that while virtually all the computer hardware we wanted was available, software was basically not applicable. We spent almost three times that amount in our own in-house software development over the years as we have on hardware. You have to plan on those types of expenditures if the system is really going to work. You have to look at having an integrated system which can grow with the corporation.

Our basic system uses a Hewlett Packard 9000 series 32 bit processor, and we have a shared resource management system. This is the fastest equipment available right now, and it's probably the right direction rather than our main frame direction. We look at going both directions. The shared resource management approach gives us capability of having almost unlimited units connecting the others, sharing the resources through a mainline data-storage area, and we can hook up to our system. Right now we're running five separate units on it, plus one up in Cambridge. We can run 140 or 150 units with no problems.

SSCAD is menu-drive type program. Figures 9 and 10 show two sections of menu-driven system. We can teach people how to use the system in one day. We often have architects and engineers coming for one-day sessions at Space Structures to design their projects. Within an hour's time they can be using the system. It is truly user friendly. In most of the computer systems you're keypunching in numerical information. You really want to be putting in graphical information. You want much more sophisticated programs. That is where we have spent our money.

Figure 9 shows how the menu basically has soft keys on it. You hit, let's say, number one, preprocessing menu. You bring it up (Figure 10), and you say you want to generate a space frame geometry. So you hit another one again, and you can get it to generate all different types of forms and shapes. In space frames, you can do horizontal, vertical, sloped, towers, trusses, multi-layers, pyramids, multiple plates, steps, conical domes, cylindrical, anything the mind can imagine. The idea of a space frame as being a little horizontal form is very much limited in network thinking. Network thinking gives you the capability of looking at a lot more different forms, and you get efficiency out of form.

Figure 11 shows a design for a hanger for a 747, a large, curved form. For this aircraft, you need 196 feet clear span going into it, and the SSCAD system shows the types of forms you

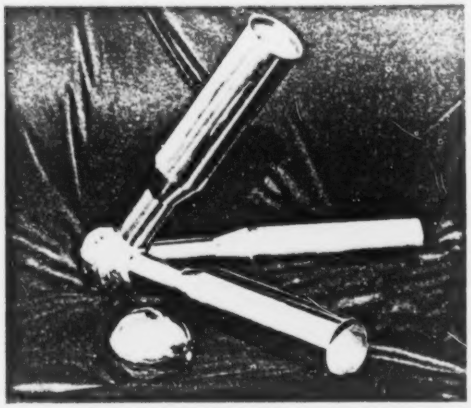


Figure 4

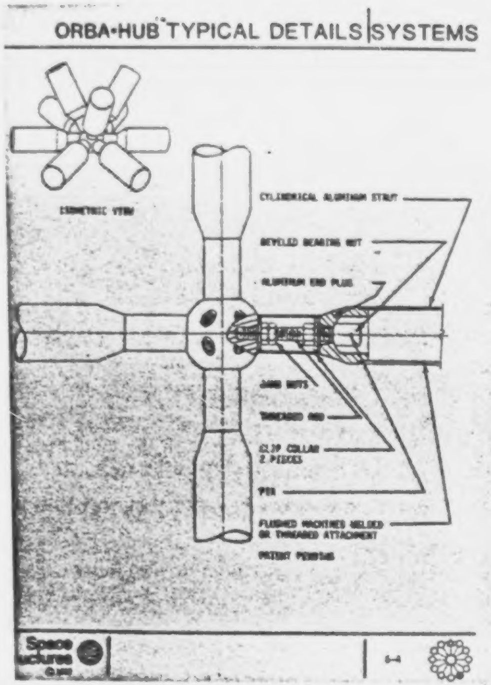

ORBA•HUB TYPICAL DETAILS
SYSTEMS
ISOMETRIC VIEW
CYLINDRICAL ALUMINUM STRUT
BEVELED BEARING NUT
ALUMINUM END PLUG
JAM NUTS
THREADED ROD
CLIP COLLAR 2 PIECES
PIN
FLUSHED MACHINES WELDED OR THREADED ATTACHMENT
PATENT PENDING
Space Structures
6-4

Figure 5

can generate. This form was generated in less than two or three minutes on the computer. You basically define the outlines of the structure. You can generate the form. You can manipulate and transform it.

Using color coding, we can color the outer members, the diagonal members, the inner members. The program enables the user to look at a drawing and modify it, and make design decisions and look at the options.

We find often when architects come to our operations and spend a day with us designing in their particular project; we can review 20 or 30 design concepts. In contrast, in the design profession, you say 50 percent of the time is spent pushing a pencil. The result is that often the first design on the paper typically is the last design on the paper. It doesn't give you much flexibility.

We went into network design because with the complexity and the sophistication of buildings, you want the capability of many different forms and shapes.

Figure 12 shows a ridge type of form, a Stroh's Beer project we're building for a retrofit project in Detroit. The geometry here was generated in less than one minute, the SSCAD system is all graphically oriented.

Figure 13 is a bottom view looking from the fifth floor below. The architect wants to say, "What am I looking at up inside the building?" So we said we'll move you in space down, and look up inside the building itself.

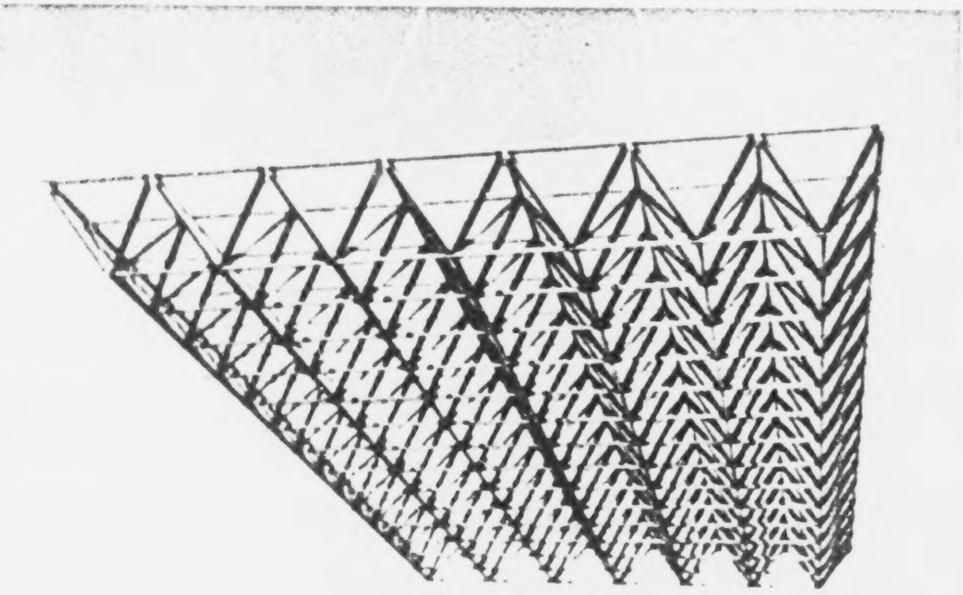
Figure 14 is a multiple folded type plate form, joins two buildings together, built over in Somerset, New Jersey. Again, some new forms which can be appropriate for the particular application.

In network design, you can create almost anything your mind can imagine. Basically you can take your visions and you can put them into reality.

A multi-folded plate for an entranceway for a corporate headquarters, an exciting type of forms. The folded plate is one type of space frame form which has a lot of advantages.

You can also marry structures together. Figure 15 shows a cylindrical form with a dome on top. This is a structure we did for the U.S. Steel Corporation for an aquatic application for

Figure 6



a tanker top which we did about six years ago.

I want to show you what the computers can do besides generating just the graphics and the design space. That's only about ten percent of the potential use of the computer systems in the whole design and fabrication process.

This is a drawing which is color coded basically showing a structure. I'll take a new GSA building built in Boston. It has a big atrium, 90 feet by 120 feet. With computers you can basically see how the structure performs. We can simulate the deflection that might result from a snow load and model it very quickly. Figure 16 shows just the top members. You can see how the geometry shows the plate action. You can see the deflection of the structure towards the center, and this way you can check it graphically. You can exchange so much more information, how a structure behaves, how it works, using the computer system.

Different load magnitudes are shown by color coding using the eight different colors on the screen. You can show where the highest compression loads are, what the highest tension loads are. Computers can give you a feeling for the network and new design freedom which you couldn't have by doing it by hand no matter what happens. So the technological development of the computer systems have allowed the development of network systems.

The system also drives plotters which we use to produce assembly drawings of the structure. Everything's numbered, the different hub types, all of the different strut types. The members are numbered so you can ship it out in the field. It takes about six minutes to draw it like this, where by hand it would have taken us eight hours three or four years ago. This gives us gigantic productivity gains and hundred-, somtimes thousand-fold reduction in time and expenditures needed to design the structures.

The programs take the geometry and the loads and convert them into actual fabrication drawings. Then we run computer-controlled equipment like our Wasino equipment, Japanese machines which are computerized controlled. Basically, we convert our design output into paper tape forms or magnetic-tape forms for production instructions.

We've been able to reduce all of the hand op-

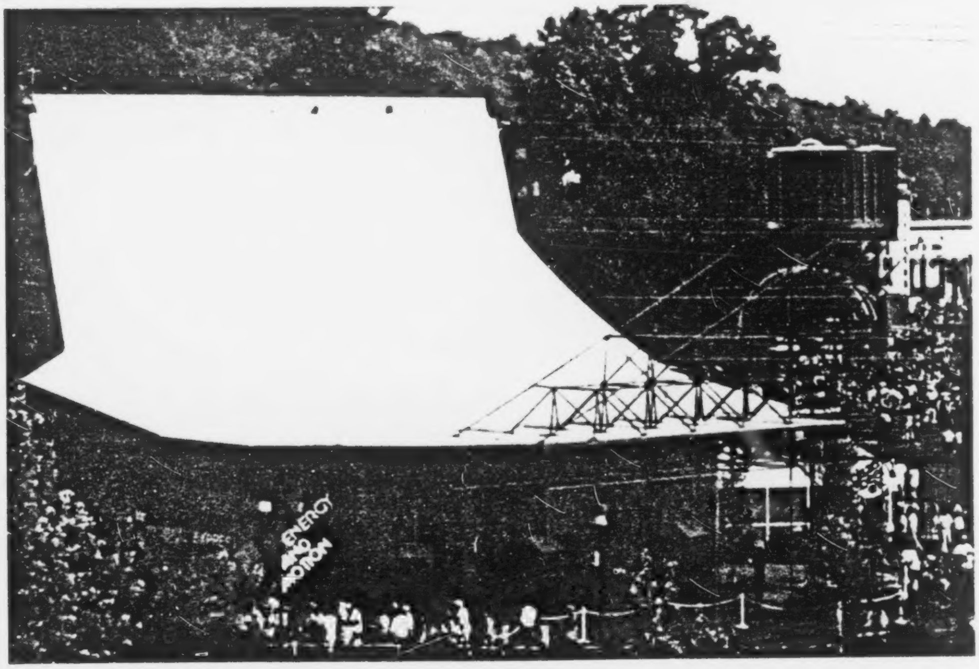
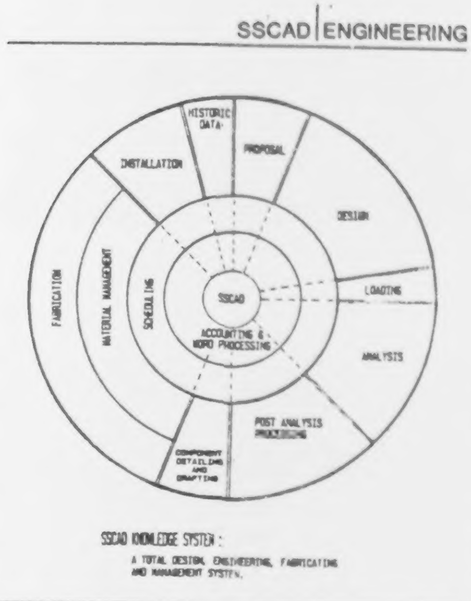


Figure 7

Figure 8


SSCAD | ENGINEERING
HISTORIC DATA
PROPOSAL
INSTALLATION
DESIGN
LOADING
ANALYSIS
FABRICATION
MATERIAL MANAGEMENT
SCHEDULING
SSCAD
ACCOUNTING & WORD PROCESSING
POST ANALYSIS PROCESSING
COMPONENT DETAILING AND DRAFTING
SSCAD KNOWLEDGE SYSTEM:
A TOTAL DESIGN, ENGINEERING, FABRICATING AND MANAGEMENT SYSTEM.

erations used to machine something. You create a new design freedom. You create new types of quality control because it's computer run and computer generated. There are fewer errors occurring, and the system gives you the capability of variation very easily because we've standardized the process. The standard thing in Space Structures is how we design, how we exchange that information, not the final end product. That means the network created can be very variable to meet the particular project's form and requirements.

What we can do with the system is easily generate a drawing like Figure 16, a bank structure with the whole space frame as the whole network.

Figure 17 shows the actual structure under construction. In this case, it's built on the ground, off to one side of where the actual foundation is, and assembled. It's an 80-by-80 foot space frame over in New Jersey. It's a bank building, and you just lift the structure up, being relatively light weight, working in aluminum. You lift the structure up, put it in place, and it basically starts to give you more and more of the structural form assembled as a network.

Figure 18 shows a conical form, using the ORBA Hub system, which certainly would not have been possible without our system. Every hub and each different row is different in the geometry and its orientation. Computer-controlled machines can generate those easily.

Figure 19 shows structure assembly for a project we did for Skidmore, Owings & Merrill in Chicago. We assemble it in three sections, lift it up, put it in place, the main entranceway for this office building, and here's what it looks like from the inside. Again, the cone form gave SOM a new shape, a new form they could easily use. Somebody could easily fabricate it.

Figure 20 is a look up through the structure itself. Figure 21 shows a barrel arch form, which has certainly become very much more popular during the last two or three years. People are learning the value of the old idea of the arch which was a great shape back in Roman and in medieval architectural times. Somehow it became out of phase because the new materials didn't allow it to be built very easily. With more sophisticated building technology, you can easily go back to the value and the benefits of using the arch type of shape.

Figure 22 shows some of the hanger projects we're building throughout the world. We're finishing one at Miami International Airport, a 226-foot clear span. Figure 23 shows how the structure is assembled. We assembled it in three sections on the ground, or multiple sections, depending upon its length and the design requirements. The structure is built out of aluminum.

Figure 24 shows a step form at 1300 New York Avenue in Washington, D.C., we are doing for Skidmore, Owings & Merrill. Figure 25 is a look up through the structure itself.

Different networks can have different forms and shapes. Figure 26 shows one being built in Culver City out in California right now.

Dome structures are also possible. Figure 27 shows a dome stadium, designed for Toronto, capable of opening and closing. We're talking about worldwide the building industry not being locally oriented. If you get into new technology, it opens up the marketplace. Probably about ten percent of our work is done overseas.

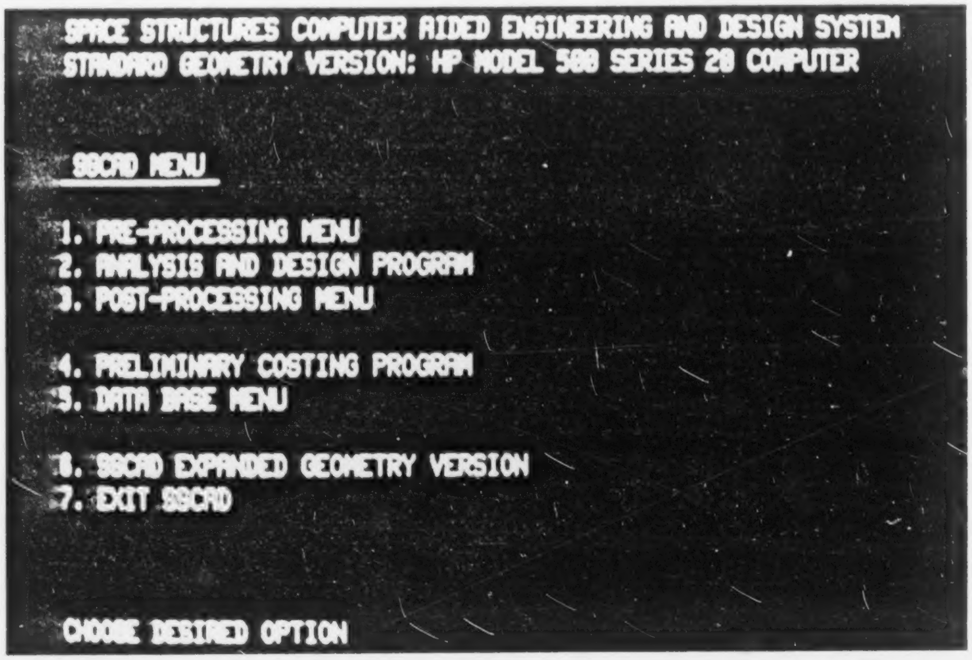
Tomorrow we see our movement where we're going to answer the phone at Space Structures within three or four years. Somebody is going to call up and say, "I want to build a space frame." The question will be back, "Is it terestrial, aquatic or space application?"

We have a new division at Space Structures called Starnet Structures which is going after the Space Program. It is the 'Job Site in the Sky Program.'

Figure 28 is a part of a Space City that we have developed. We have our applications in to two NASA contracts right now. We've been talking to Grumman, Lockheed and Spar on possible joint ventures going up to the Manned Space Station Program.

The drawings are conceptual, what we call cartoon drawings in the aerospace business — what something could potentially be like. But you have to think, if you're in the building industry, on a galactic scale or else you're going to limit yourself, and the Japanese are going to come in tomorrow.

Well, lets start thinking, you know, twenty



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SPACE STRUCTURES COMPUTER AIDED ENGINEERING AND DESIGN SYSTEM
STANDARD GEOMETRY VERSION: HP MODEL 500 SERIES 20 COMPUTER


SSCAD MENU

1. PRE-PROCESSING MENU
2. ANALYSIS AND DESIGN PROGRAM
3. POST-PROCESSING MENU

4. PRELIMINARY COSTING PROGRAM
5. DATA BASE MENU

6. SSCAD EXPANDED GEOMETRY VERSION
7. EXIT SSCAD



CHOOSE DESIRED OPTION
```

Figure 9

years ahead of them and start moving in those directions.

We should quickly talk about how structures should have some structural art form to them. We're creating structures; we're creating environments. They have to have a value to them other than just enclosing and being a climatic envelope. They should have a good design to them, and the structures are more and more with network design being able to be expressed as structural forms, and I think it has a great value like that.

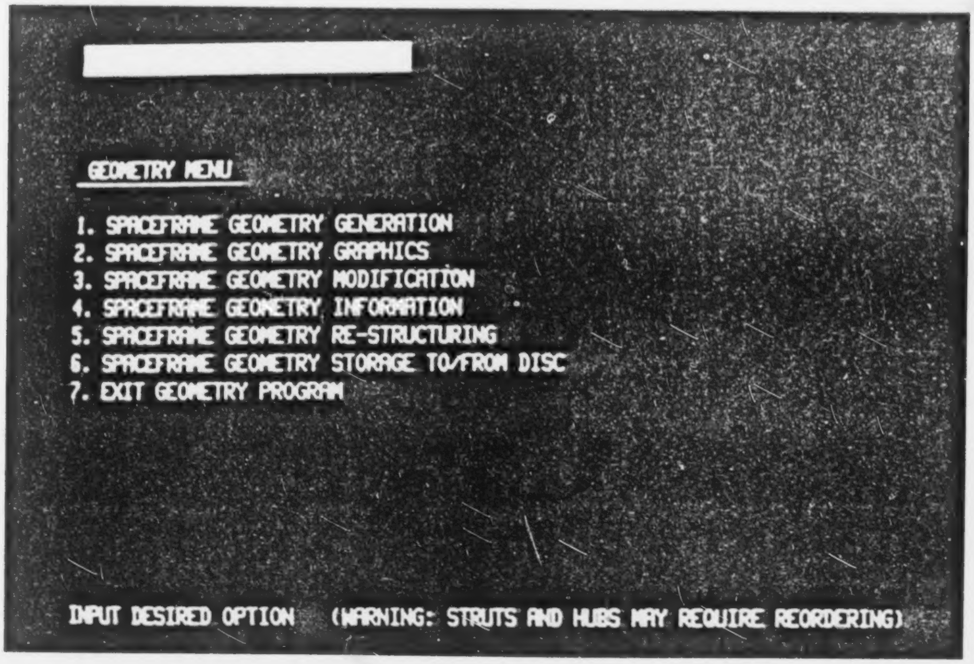
Figure 29 is Caesar's Palace out in Las Vegas, and is an example of all the structures at Space Structures which are designed around three basic goals: structural efficiency, project economy and system elegance.

What's the team work that's being put together? We see ourselves as part of a new team. In the past, teams typically combined architects/engineers, the general contractor and the owner. We see two new members becoming involved in the initial design stages of the project. Ourselves as a systems specialist, and a construction manager.

Almost 80 percent of all of our contracts are negotiated; more than 50 percent of them right at the front end of a project, typically under Phase One of the contract. We work with architectural/engineering firms and help them in design and development during Phase One of a project. With the computer systems, you're able to budget the project on the first day and trade ideas back and forth. With the new team we hold meetings at the beginning of a project, and get everybody who is going to be involved with the project at initial meetings. You can save owners hundreds of thousands and millions of dollars in a project if everybody who is a major participant in the project comes together. We have spent some long, twelve-hour sessions on some projects. When everybody walks out of the door, there has been participation. The areas of responsibility and their direction are pretty well tied down. You can pick up from six months to a year by expediting a project on the way. The marketplace has recognized how important this organizational strategy is and has responded.

Wendel R. Wendel is the President of Space Structures International Corporation in Plainview, New York.

Figure 10



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GEOMETRY MENU

1. SPACEFRAME GEOMETRY GENERATION
2. SPACEFRAME GEOMETRY GRAPHICS
3. SPACEFRAME GEOMETRY MODIFICATION
4. SPACEFRAME GEOMETRY INFORMATION
5. SPACEFRAME GEOMETRY RE-STRUCTURING
6. SPACEFRAME GEOMETRY STORAGE TO/FROM DISC
7. EXIT GEOMETRY PROGRAM

INPUT DESIRED OPTION   (WARNING: STRUTS AND HUBS MAY REQUIRE REORDERING)
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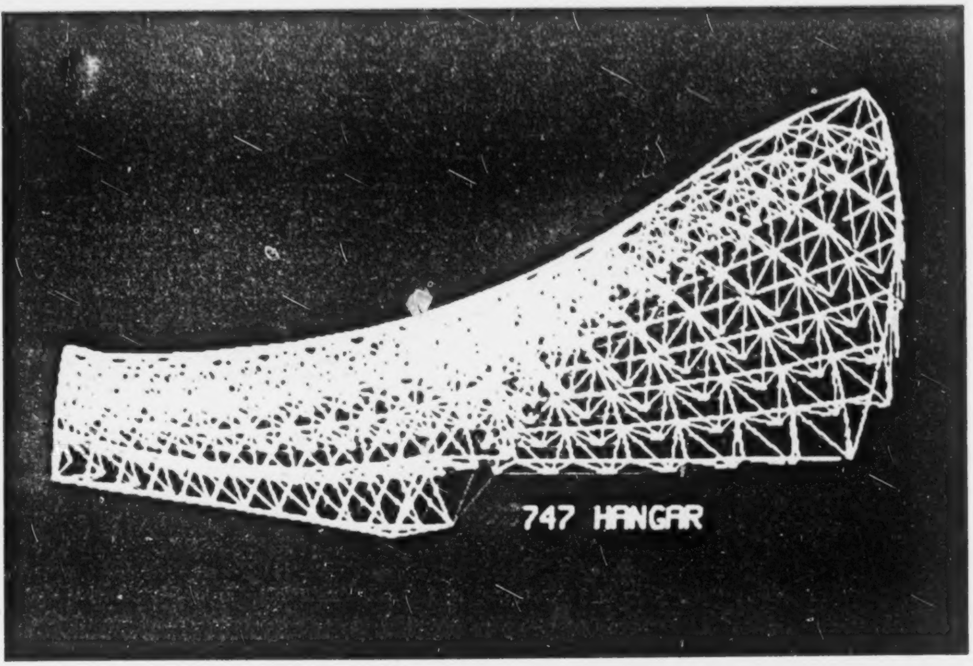


Figure 11

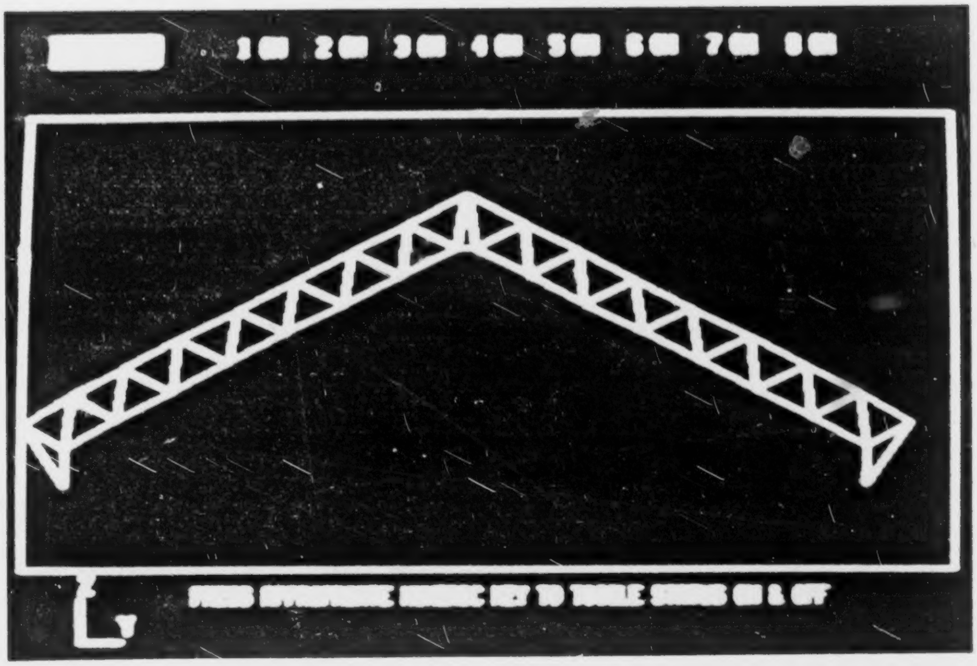

1
2
3
4
5
6
7
8
Z
Y

Figure 12

Figure 13

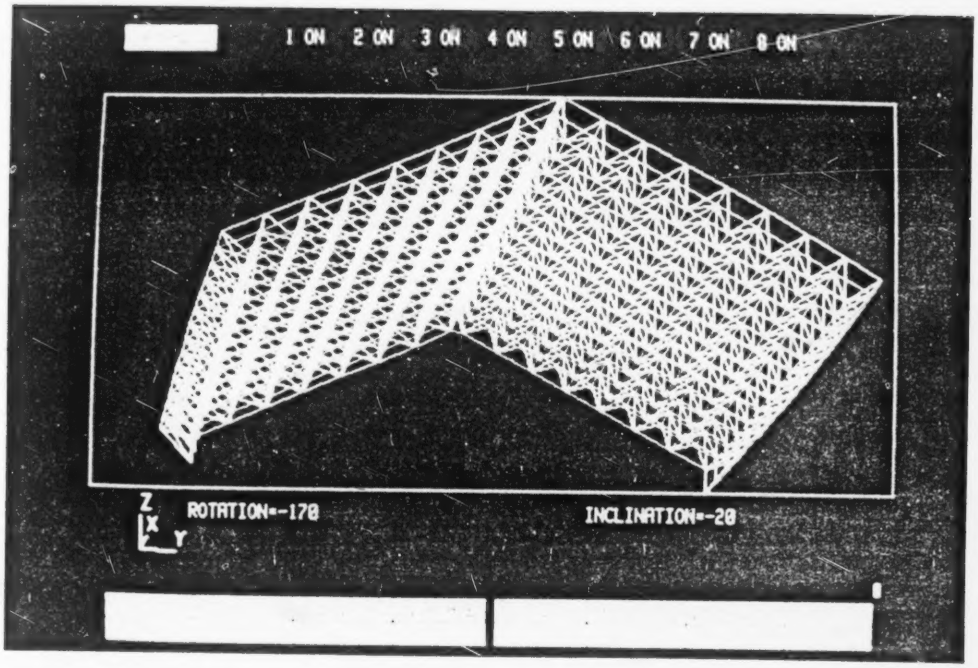
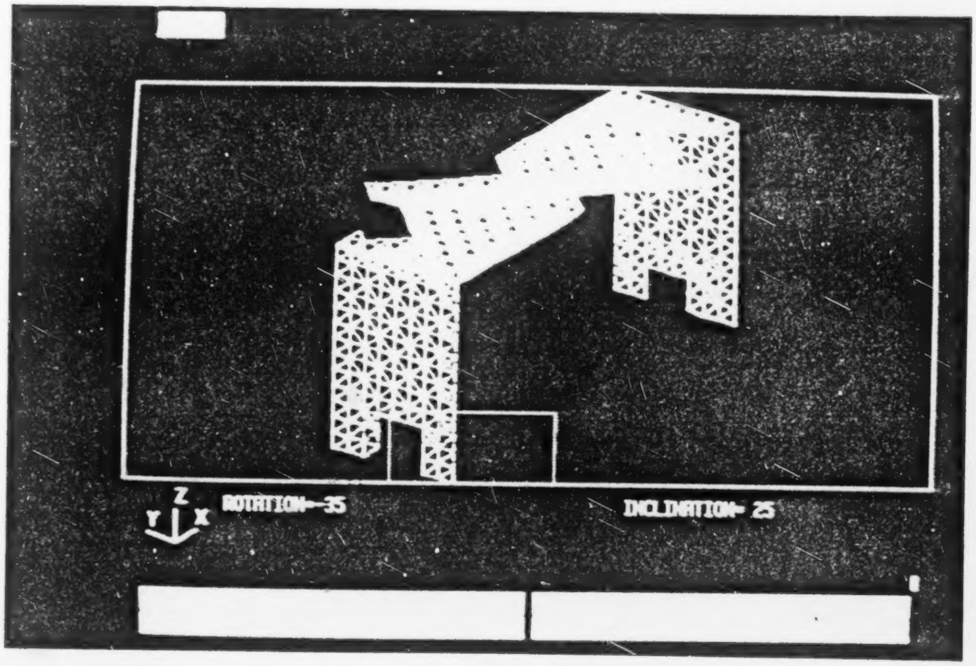

1 ON 2 ON 3 ON 4 ON 5 ON 6 ON 7 ON 8 ON
Z
X
Y
ROTATION=-170
INCLINATION=-20

Figure 14


Y
Z
X
ROTATION=-35
INCLINATION= 25

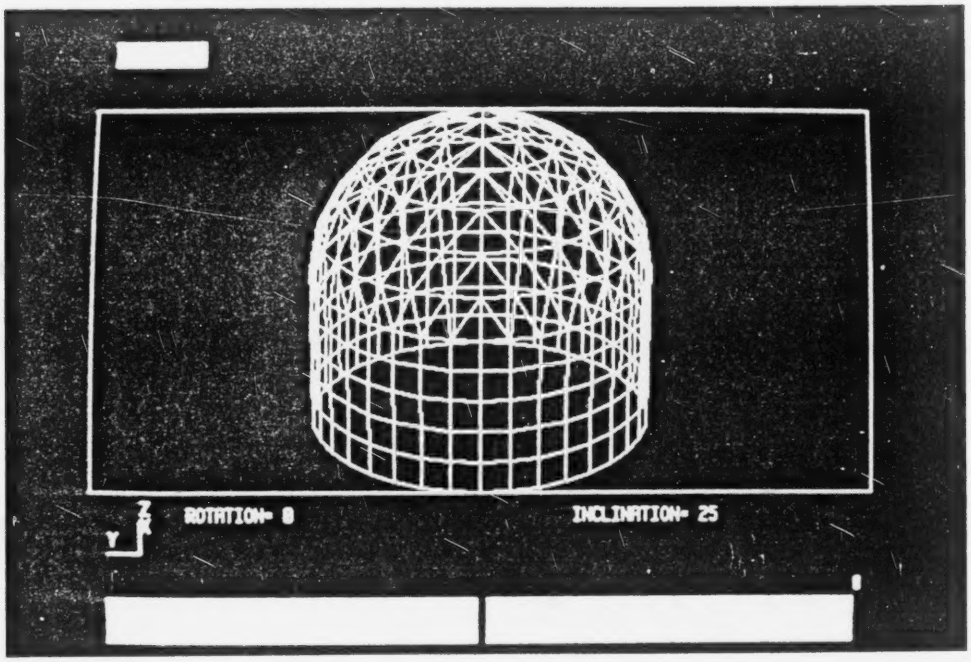
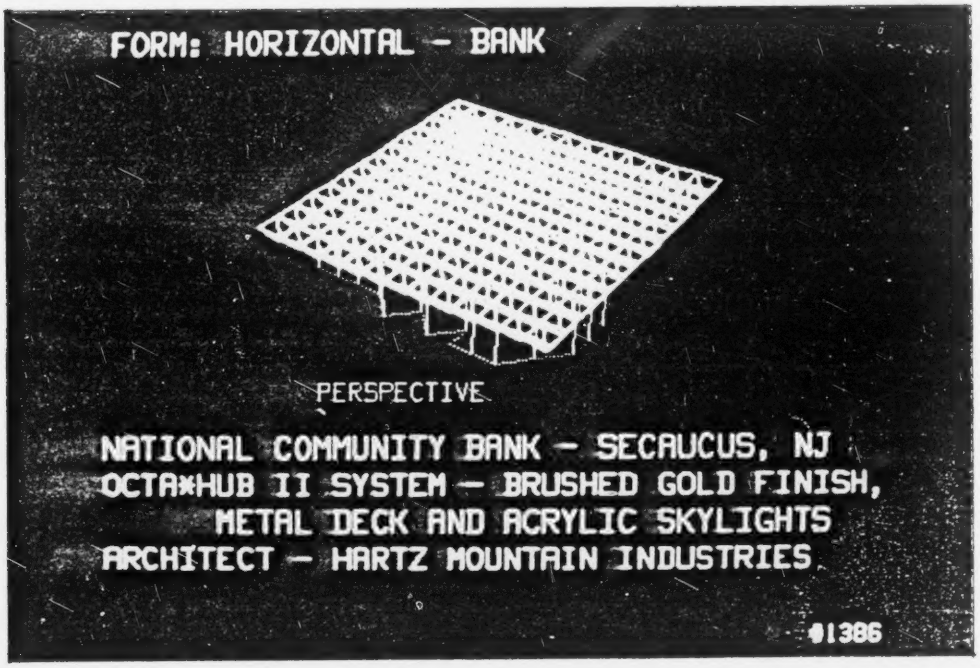

Z
Y
X
ROTATION= 0
INCLINATION= 25

Figure 15



FORM: HORIZONTAL - BANK

PERSPECTIVE

NATIONAL COMMUNITY BANK - SECAUCUS, NJ
OCTA*HUB II SYSTEM - BRUSHED GOLD FINISH,
METAL DECK AND ACRYLIC SKYLIGHTS
ARCHITECT - HARTZ MOUNTAIN INDUSTRIES

#1386

Figure 16

Figure 17

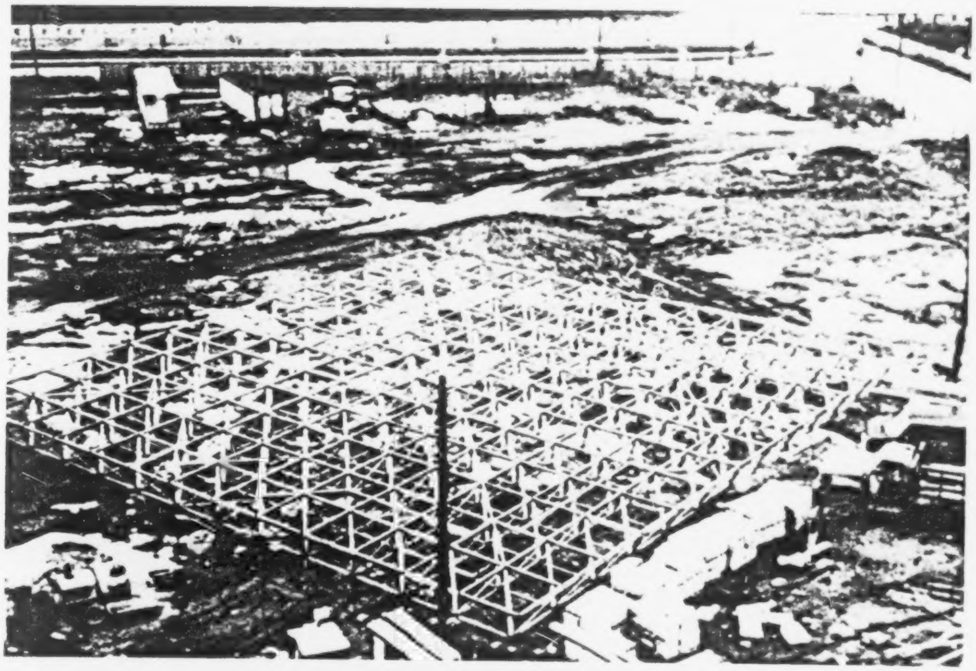
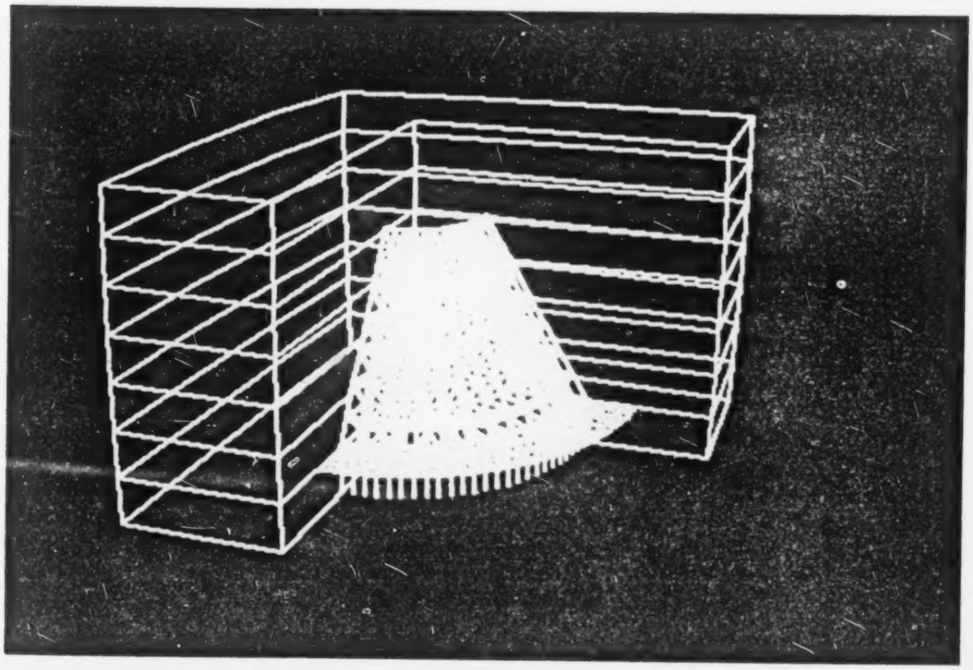


Figure 18



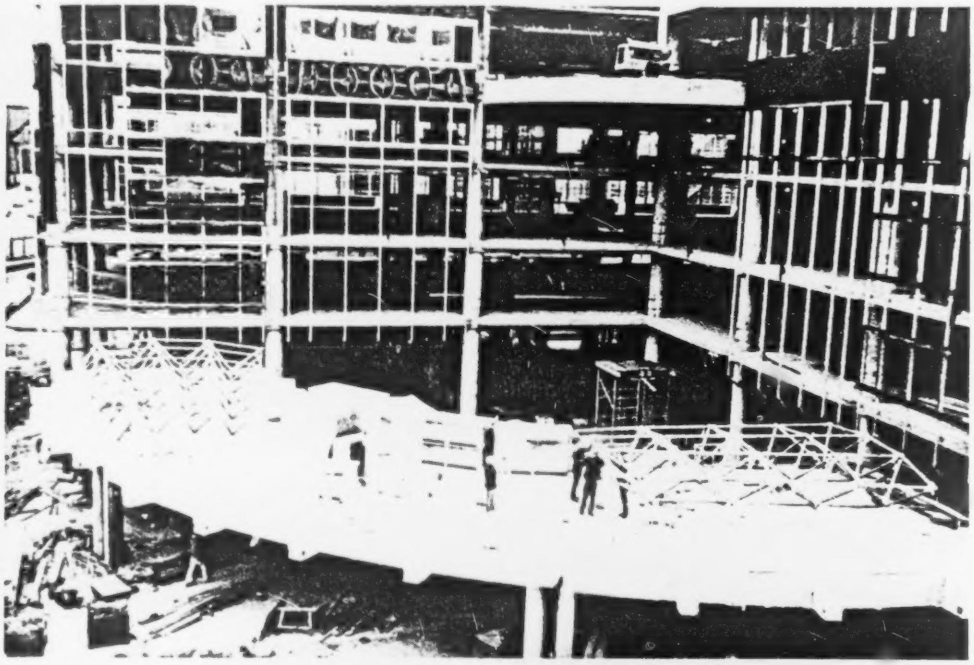


Figure 19

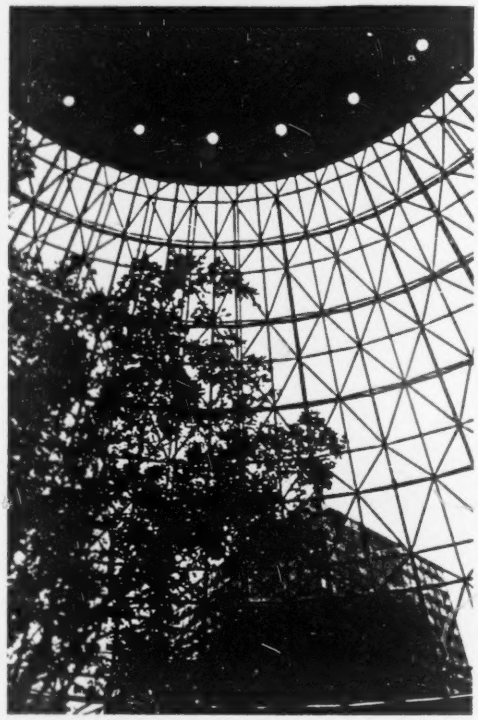


Figure 20

Figure 21

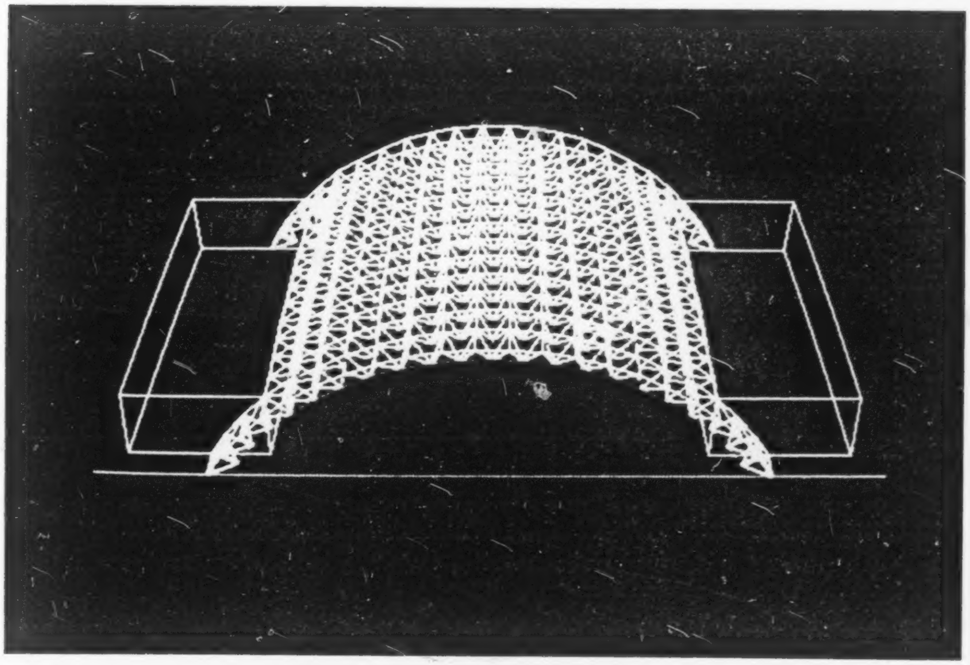
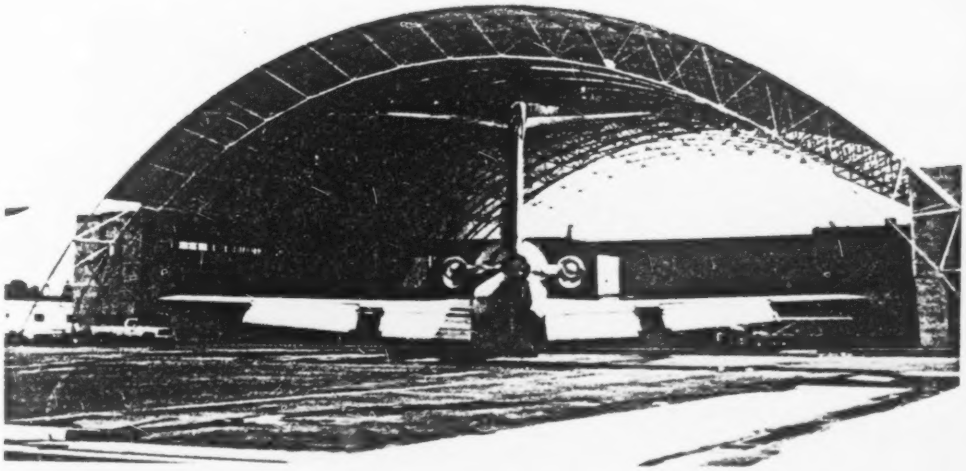


Figure 22



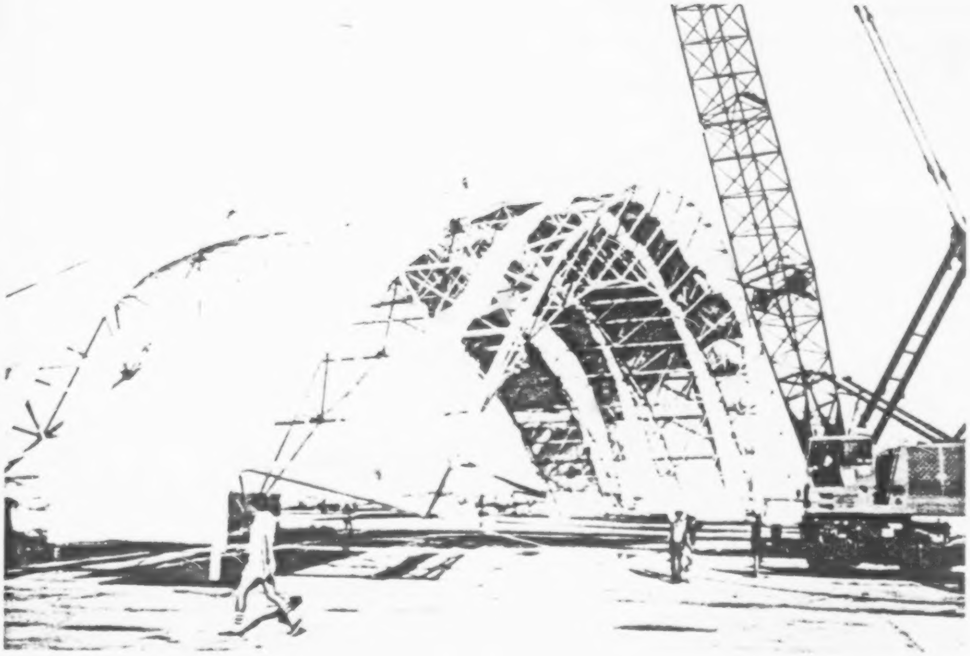


Figure 23

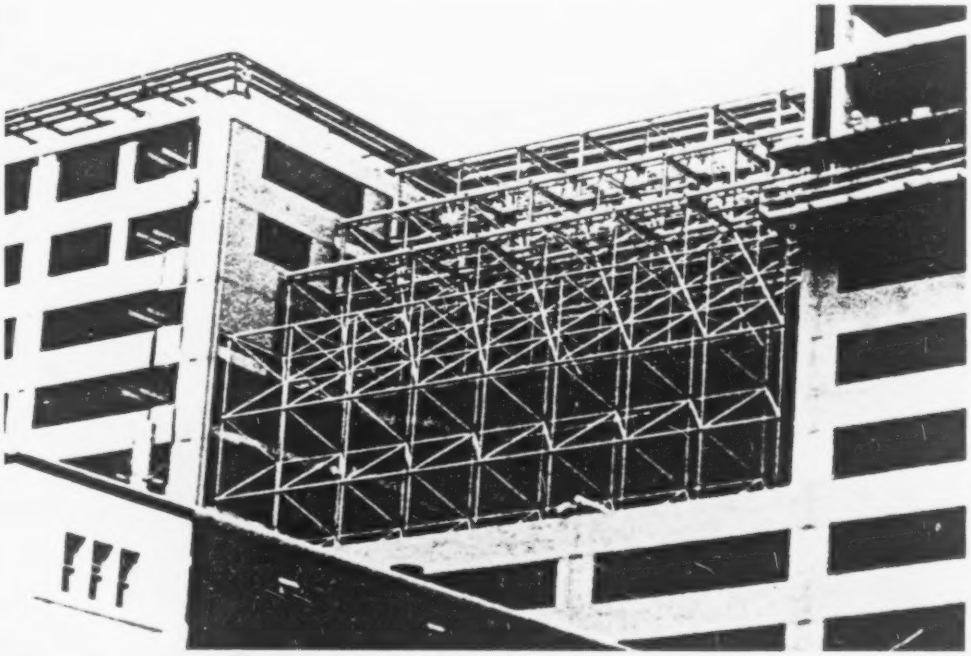
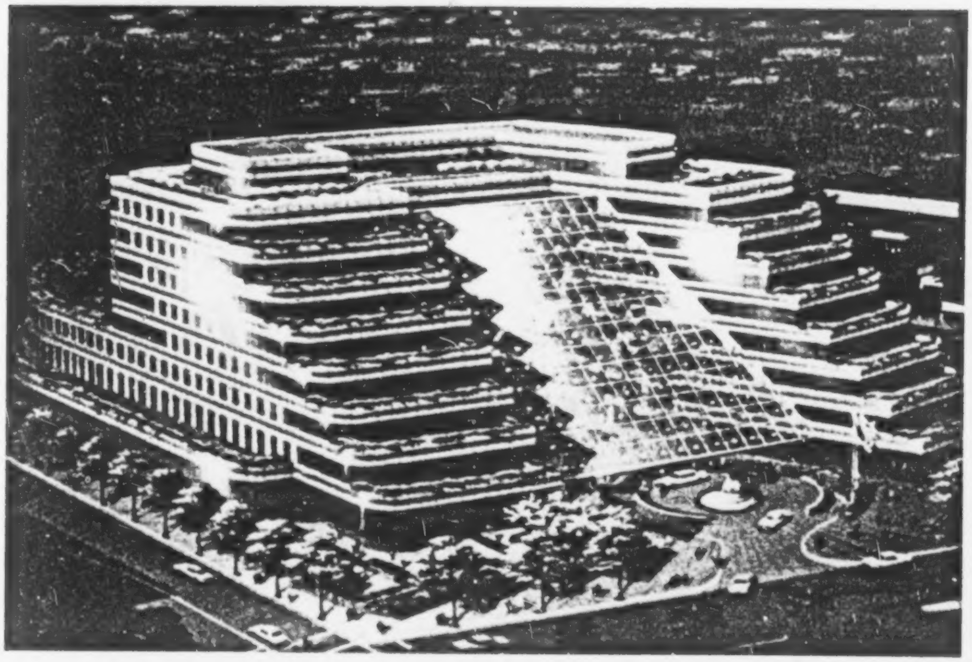


Figure 24

Figure 25

Figure 26



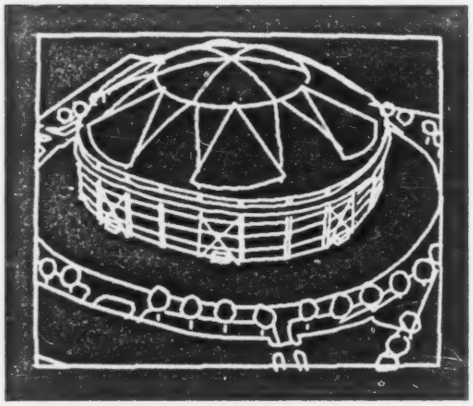


Figure 27

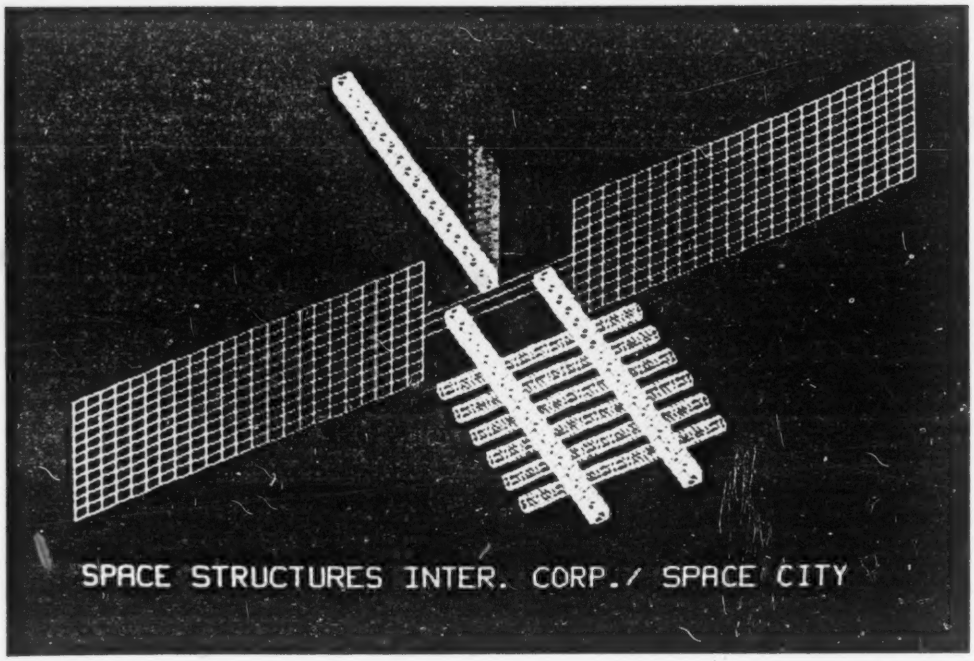
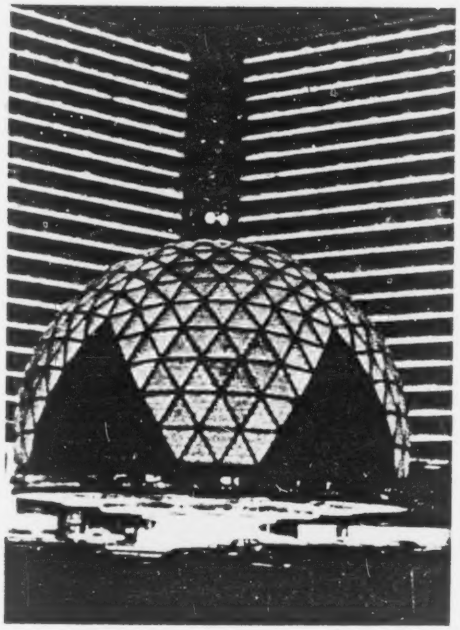


Figure 28

SPACE STRUCTURES INTER. CORP./ SPACE CITY

Figure 29



8

Materials
Albert Dietz

Albert Dietz

I might start off by saying that a great deal of what I was going to say has already been said, but I'll have to repeat some of it just the same.

First, I want to make a few general observations. I don't know of any new or revolutionary materials that are being used now or are immediately in sight, unless the space industry comes up with some surprises.

That depends, of course, on what is meant by "new" and "revoluntionary." Some people might consider that some things I want to talk about are new and revolutionary, but to me they are not. They're in the evolutionary stage. They may have been considered new and revolutionary fifteen, twenty, twenty-five years ago. They are now going through the stages that every new material has gone through, the long, slow process of development and acceptance by the industry.

Masonite took about twenty-five years to become a broadly accepted commodity. Gypsum board is another instance. Even portland-cement concrete had to go through a long period before it was generally accepted. That's been true of building materials right down the line, and it's true of the materials we're talking about today.

We can't discuss all materials. I'm going to concentrate as a case on the new group of materials and composites based on polymers. I might review, however, very quickly some of the older types of materials.

We have structural, nonstructural and auxiliary materials: Structural being those that carry loads, including steel, concrete, timber, masonry; nonstructural, such as flooring and insulation; and auxiliaries, those materials such as adhesives, sealants and coatings, which are used in conjunction with other materials and may not be seen at all. There are developments in all of them but they are not particularly revolutionary.

Another classification of materials is non-metallic, metallic, organic, wastes and byproducts. Developments are occurring in all of them but none really revolutionary. There is one area, however, in which a great deal can be done, and in which there are real opportunities, and that's in waste and byproducts. We're tearing our cities down and having a terrible time trying to find out what to do with the rubble. We ought to be doing a great deal more to determine how we can reuse that rubble rather than throw it away and bury it somewhere. That's a tremendous challenge.

Byproducts are another great challenge. If and when we ever solve the sulphur-dioxide emissions problem, we're going to have millions of tons of sulphur in one form or another, and what are we going to do with it? Byproduct gypsum is one possibility, for example, and there are many others. Sulphur can make a very good concrete. It can also make a very good road building material. There are many wastes and byproducts, obviously, in which we ought to be doing a great deal more than we are, agricultural wastes, for example.

The wood industry has gone a long way. What used to be considered wood waste and was just burned because we didn't know what else to do with it now goes into chipboard, a very valuable product. We're using waste species we never had any use for before, making them into strandboard and other boards, valuable products. These boards were made possible by the advent of the high-strength synthetic adhesives. This introduces the field of combined materials, or composites, the subject I'd like to concentrate on.

What types of composites do we have? I'd like to put them into three principal classes: particulate, in which particles are embedded in a matrix; fibrous, or fibers embedded in a matrix; and laminar, composed of sheet materials, bonded together and possibly impregnated. Under laminar, is the special subclass of sandwiches.

The most important particulate building material is portland-cement concrete. It has its limitations, and by adding polymeric materials, we can come up with some rather striking improvements.

The first approach is to impregnate standard concrete with perhaps five to eight percent of a material such as acrylic, to produce a three to fourfold increase in compressive strength. Going from 5,000 to 20,000 pounds per square inch has not been unusual. Hardness also goes up, as does resistance to impact. Resistance to freezing and thawing increases because the pores have been filled. The difficulty is it's a slow, arduous, expensive process, requiring autoclaving or other means of impregnation and curing.

The second approach is to incorporate the polymer while mixing the concrete, with variable results, some very good and some very poor.

The third, is the substitution of a polymer for the portland cement. In other words, concrete is bonded with a polyester, for example, instead of portland cement. The recently-built Harvard Medical School Building (Figure 1) is an example. Wall panels are three inches thick, with facings one-inch thick glass fiber-reinforced-polyester concrete and core one inch of plastic foam. No lengthy cure is needed, panels can be made today, erected tomorrow. We don't have a fifty-year history of the material, a problem common to many of new materials, I shall come back to this.

In fibrous composites, a great deal is being done. We're taking a bit of a lead from the space industry here in a crude sort of way. I should like to use several examples.

The first is the United States building at the Brussels World's Fair in the 1950s. (Figure 2) It has a 300-foot diameter, cable-supported roof with translucent sandwich-type panels consisting of glass fiber-reinforced polyester on an aluminum grid; light in weight, tough, strong, and now being used quite widely for industrial, commercial, religious and school buildings: roofs and sidewalls.

The next example illustrates the use of glass-fiber-reinforced plastics in shell forms. One of the problems with these materials is their low

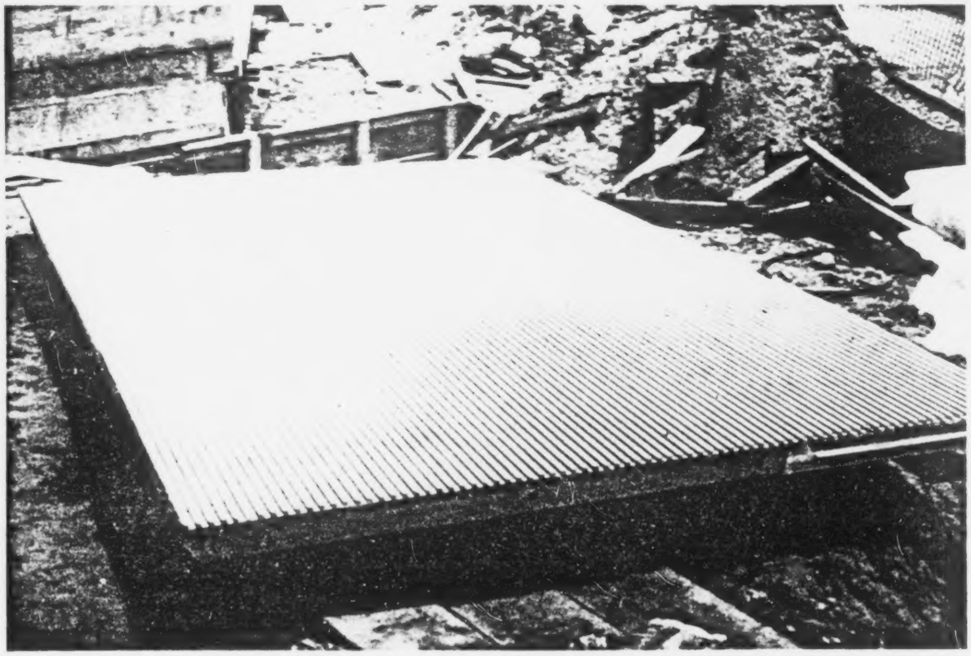


Figure 1

Sandwich wall panel with polyester-concrete facings and foamed-plastic cord.

elastic modulus. Consequently, they have low stiffness, and in order to make them work at all, curved inherently-stiff shapes must often be used.

Figure 3 shows the pavilions built for the United States exhibition in Moscow twenty-five years ago. They are 24 feet high, 16 feet across, with canopies one-sixteenth inch thick and quarter-inch thick ribs, the stiffness coming about more from the geometry than from the inherent properties of the material itself.

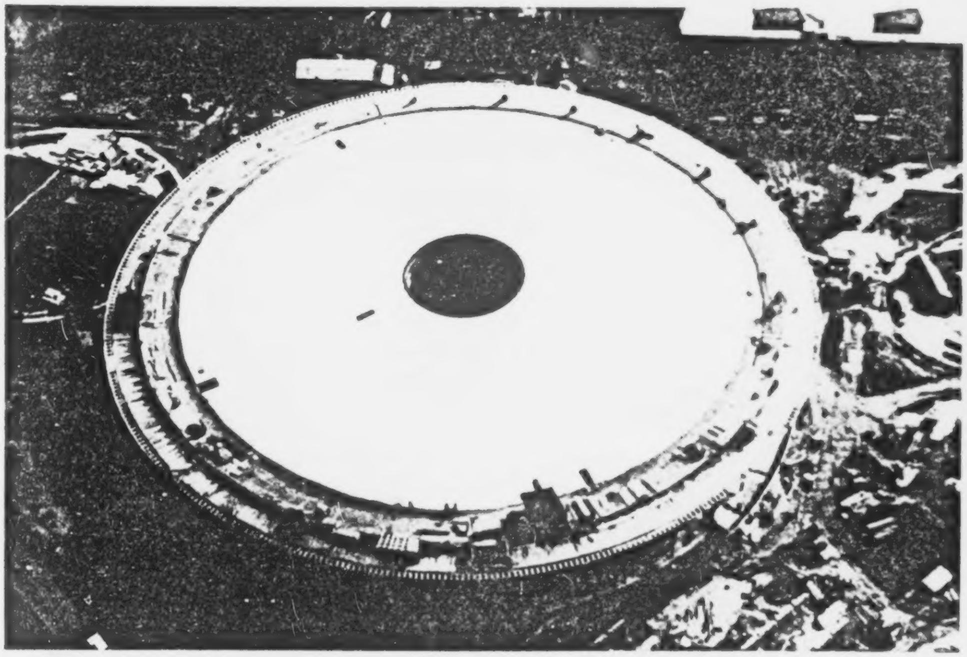
The next illustration, (Figure 4), is another shell form, the so-called House of the Future, built in Disneyland about thirty years ago. It is still the house of the future, but it was a pioneering use of the shell in the form of a monocoque. It was originally designed to be up for one year, was left up for ten and then posed a real challenge to the wreckers when the site was needed for something else.

Another composite application is a case history illustrating a number of interlocking factors that have to be taken into account simultaneously. About twenty years ago, the Greater London Council decided to use performance specifications for the exterior cladding of a projected series of twelve 25-story apartment buildings for moderate-income housing. The specifications said nothing about materials; but called for resistance to 80 mile per hour winds, a U factor of about 0.20, an acoustic attenuation factor of about 35, one-hour fire penetration resistance, essentially zero flame spread, minimum thickness, minimum weight, and about a thirty-year life without appreciable maintenance. No materials were specified.

Out of many conferences came a composite panel (Figure 5). The outer face was a press-molded skin of glass fiber-reinforced polyester loaded with mineral and turned out by a sports-car body manufacturer. The filling was foamed concrete, weighing about 20 pounds per cubic foot, reinforced with light wire. On the inside was gypsum plaster, reinforced with glass fiber and abestos, with a vapor seal and binder of bitumen between the gypsum and concrete. To allow for differential expansion and contraction, the outer shell was bonded to the concrete with expoxy adhesive and a thin layer of polyurethane foam.

Figure 2

Cable-supported translucent sandwich-panel roof of United States building, Brussels World's Fair.



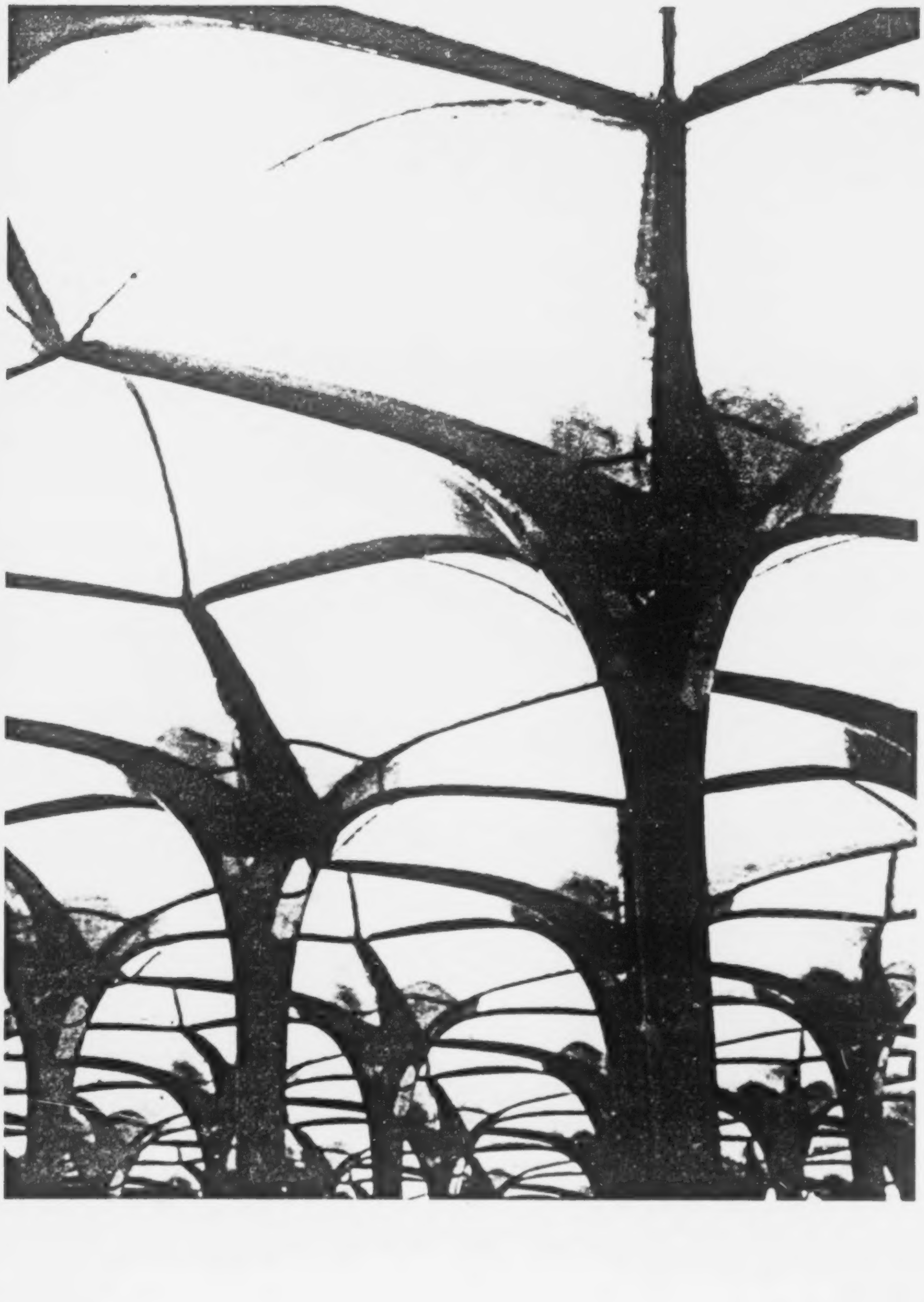


Figure 3

Glass fiber-reinforced canopies and stalks, pavilions at United States Exhibition in Moscow

This was a composite of composites. It met all of the requirements of the British Fire Research Station. It weighed 15 percent as much as standard masonry or concrete construction. The in-place cost as estimated by the builder was more than competitive with the standard construction, because of speed and ease of erection.

Four buildings were built, and then the other eight were scrapped, not because of any technical problems. It was a technological success. It was a sociological failure. People refused to move into 25-story buildings. They just didn't want to live in them.

When only four buildings were built instead of twelve, the economics changed. Subsequently, five-story buildings were built, and standard masonry construction was just as competitive as the composite panel.

This case illustrates a number of things. Performance specifications made possible the marriage of a number of different materials to perform the overall requirements. The result was generally successful. Over the twenty years the panels have been up, they have behaved quite well. There have been some blemishes which had to be repaired in situ.

The repairs, though successful, show. The patches don't match the original material, and little spots appear on the surfaces.

The heavy aluminum windows were a failure and had to be replaced, with some damage to the panels, requiring repairs. A hot fire in one apartment broke through windows and scorched the outside surface, but did not spread (Figure 6).

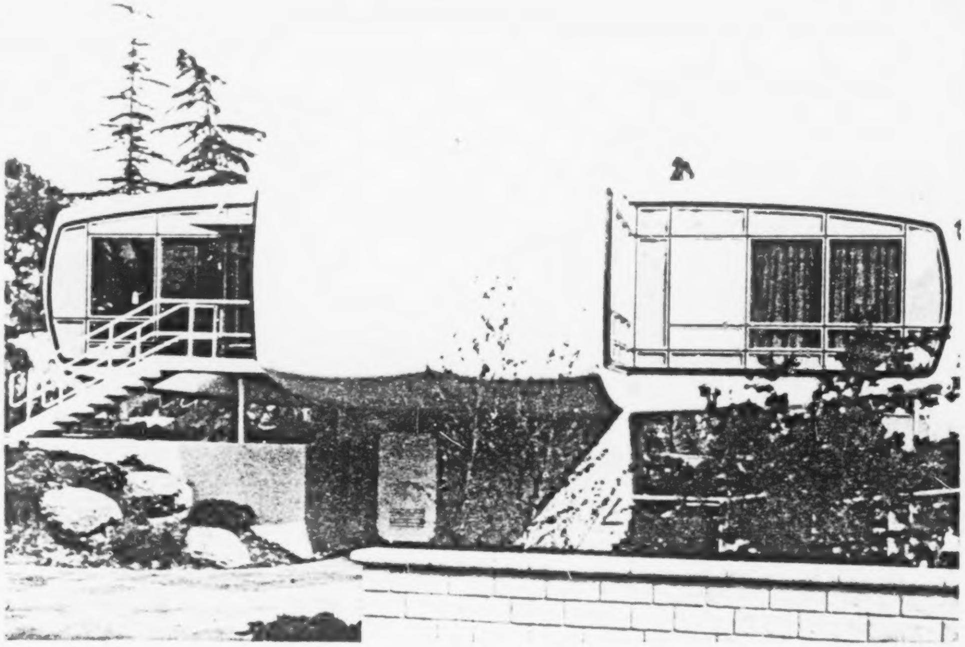
The engineers are in favor of the system, but it has not been used again.

One problem was: who would produce these panels? There was no existing industry. The little engineering firm that undertook this job had to scramble around and find a panel molder in Ohio, various suppliers in the British Isles, and bring all of the elements together in one place, where the builder assembled them off site and erected them, using the same equipment as for the rest of the building.

This is a capsule illustrating some of the things that can be done with composites, and some of the problems that occur when we try to

Figure 4

Glass fiber-reinforced monocaque structural cantilevers, House of the Future, Disneyland.



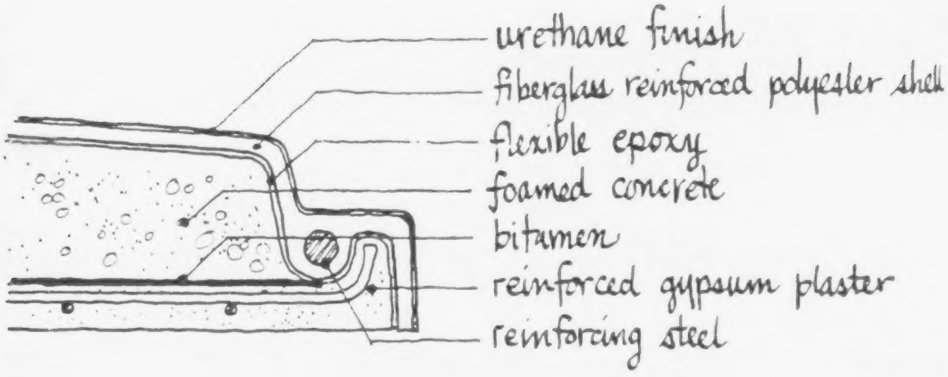

urethane finish
fiberglass reinforced polyester shell
flexible epoxy
foamed concrete
bitumen
reinforced gypsum plaster
reinforcing steel

Figure 5

Composite wall panels. Greater London Council buildings.

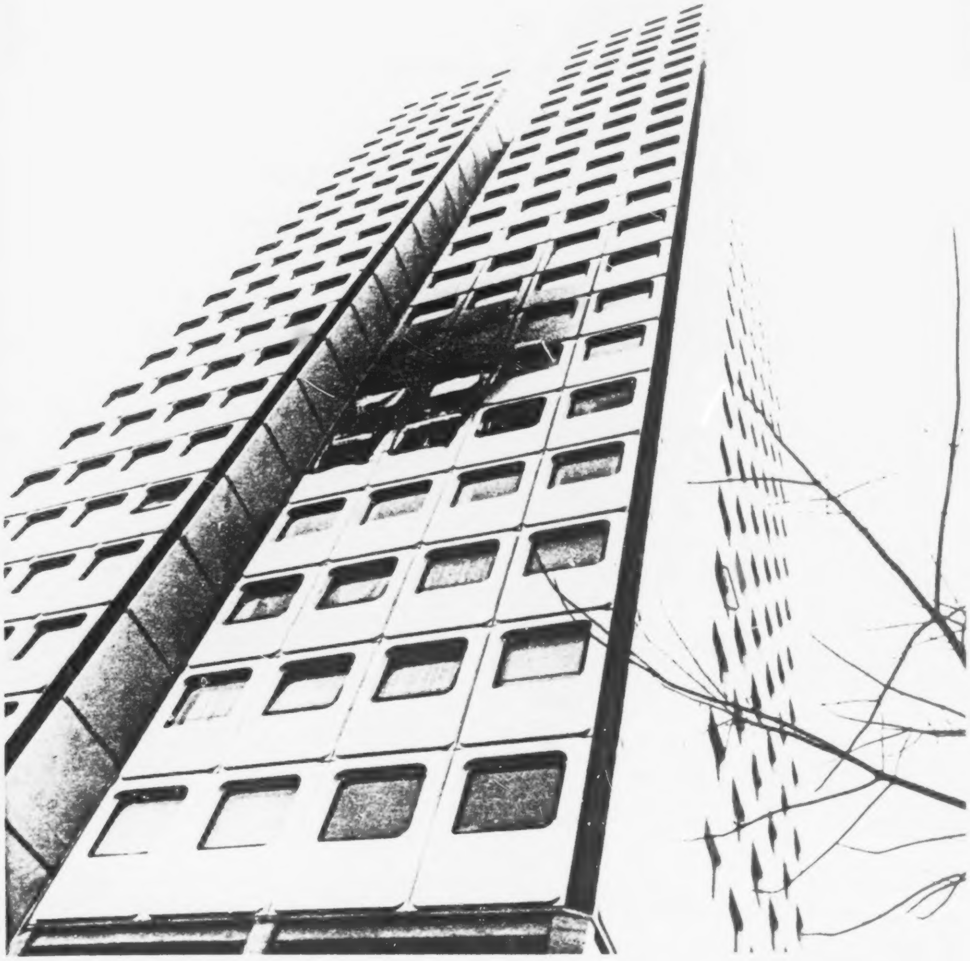


Figure 6

Greater London Council building showing the outside structure.

introduce a fairly new material.

What are some of the probable future developments? What are some of the effects on the building industry? Plastics in general and the composites by and large lend themselves best to shop fabrication. They're not good when it comes to field fabrication. You can't take a hammer and saw and cut off some pieces and nail them together. The trend is toward more and more shop fabrication of finished components, and this is where plastics and composites fit in particularly well, right in line with the trend. New processes are involved, however, with which the building industry is not acquainted. Sometimes big presses are needed, sometimes materials and product handling are different. Builders will have to get used to them.

New building forms are possible. The House of the Future, for example, looks entirely different from a standard house. The tension form for the Jedda Airport in Saudi Arabia (Figure 7), consisting of about 500,000 square feet of Teflon-coated glass fabric, is another example of a new type of form. It's a tent. At the Osaka Fair, the United States building — air-supported, vinyl-coated glass fabric — was another type of form made possible by the new materials (Figure 8).

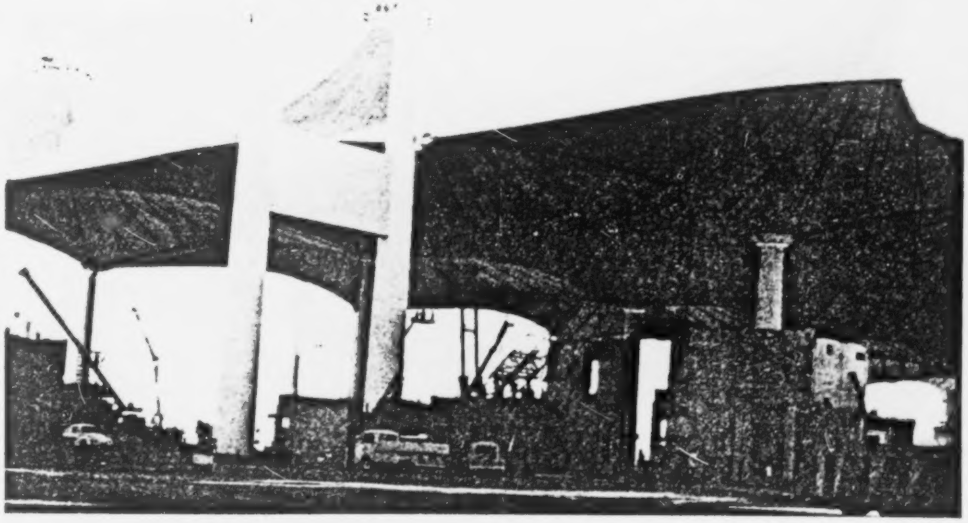
Perhaps we can make contribution to energy conservation. The plastic foams are among the best insulators that we have from the standpoints of efficiency and use. There also can be problems with them as we found out with the formaldehyde.

Perhaps we shall have contributions from the Space Program. In any event, we shall find that our usual methods of fabricating parts for buildings will undergo changes as we bring in unfamiliar materials including plastics, other polymers and composite materials.

Now, what are some of the influences affecting use of unfamiliar materials? One major influence retarding the rapid adoption of these materials is uncertainty, particularly in two directions. The first is, how do they behave in fire? Many are organic materials. Any organic material can be destroyed by a hot enough fire. So how do we get around the problem of their susceptibility to fire? Of course, we use many

Figure 7

Tent roofs, 45 meters square, Teflon-coated glass fabric, Jeddah Airport



materials in buildings that are susceptible to fire. That's not a new situation, but there are new aspects to it with respect to plastics, and the fire tests that we generally make may or may not be directly applicable to these new materials.

There's a great deal of work that needs to be done on fire evaluation generally, and not only for plastics and composites. This activity will have to be carried on somewhere.

The second question is long life, longevity. How will these materials stand up for a long period of time? Here we come to a question of definition. If you talk to the plastics people, "Oh, sure, these things will stand up for a long time."

"What do you mean?"

"Oh five or ten years." A building five years old is practically brand new, out of the box, and when you tell them, "No, we're not interested in that, but we want at least twenty-five, thirty years, perferably fifty years," the surprised reaction is likely to be, "Oh, no, we can't promise that." So there is the question. We do not have good ways of predicting long life, especially with new types of materials. This is another field in which a great deal of work needs to be done.

There are other things we could talk about: education, activities abroad, and many more.

There are several areas for concentration. I've already mentioned two. One is fire, and I mean fundamental work on fire, not just ASTM tests. These are very good tests and we have very good commercial establishments for running tests. We need fundamental research such as fire modeling and how to go from a small-scale test to prediction of actual behavior in large-scale fire. This kind of research is not the province of any one company. It will be up to Government agencies, such as the Bureau of Standards, which is doing good work, but is vulnerable to changes in government policy. Universities can contribute to such research. This type of work needs to be carried along and fully supported for an extended period.

Long-term prediction is another area. We do not yet know how to make a short-time test which will accurately predict how materials, especially new and familiar ones, will behave over

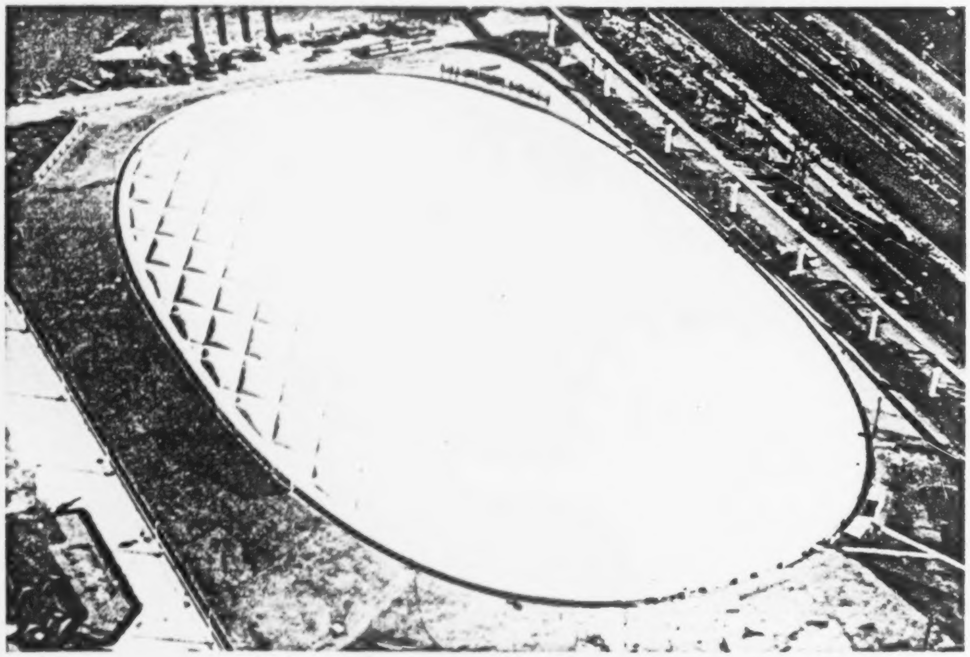


Figure 8

Air-supported vinyl-coated glass fabric roof, United States Building, Osaka Expo '70 Fair.

a long period of time. So we have our test racks facing south Florida and Maine and try to get some idea from them, but those results are both limited and slow.

Information dissemination; this has been raised before, and is a serious deficiency. Information just doesn't get around well in the building industry. There are thousands and thousands of small-scale builders, and it's hard to get the information around. It's very hard to get it together in the first place. It's there somewhere in somebody's file, but it's not getting around.

We don't know how our materials really behave in our buildings. These buildings constitute the biggest laboratory in the world, but we don't really make a systematic study of our materials in place, and therefore, we can't develop tests that will adequately predict their behavior.

The question of codes has been brought up earlier. They are important, no question about it. Codes can stand in the way of the use of new materials. The question of performance codes has been raised. A performance code calls for a needed upgrading of the abilities of our building inspectors. You can't have a performance code and just any political appointee going out looking at your buildings to determine if they comform to performance codes.

We ought to have systems of evaluations, such as are found in some of the European countries, which we don't have here. These things are among the aspects that we have to consider, and perhaps this panel should be thinking about them when looking into materials.

Albert Dietz is Professor Emeritus of the School of Architecture and Planning, of the Massachusetts Institute of Technology

9

Commercial Building Designs

Charles H. Thornton

Charles H. Thornton

I would like to address the subject of changes in building design, materials and processes as seen from the designer's side. My area of activity is the design of commercial, institutional, and multi-story residential buildings. Structural engineers tend to not get too involved in one-story, single-family residential buildings, but more in the high-rise, multi-level type of construction.

Recently in the *New York Times*, about three or four weeks ago, there was an article about the cost to construct a project in New York City which pointed out an interesting fact: To bring a condominium on line in New York City now runs $300 per square foot. One hundred dollars is construction cost, $100 is land cost, and $100 is interim financing and soft costs.

So we can sit here and address the problem of construction costs, how to do things, how emerging technologies are going to affect construction costs from a design side and a construction side, but we're really only addressing one-third of the situation. The land cost is beyond my ability to discuss, but the financing costs and the length of time and the process from the time you conceive a project to the time you occupy the project is the area in which I think a major revolution is probably going to take place in the next decade. That's probably where the major cost savings and major technological changes will occur. They're not going to be technological in the sense of high tech, but they're going to be more within the process of construction.

I'd like to address the design, materials and processes aspects. From the design point of view, computers obviously are going to be the entity which will revolutionize the design business. It's happening already. The things that Wendel R. Wendel talked about, all of that sort of thing, it's coming rapidly. It's in our office now. It's in a lot of offices — the ability to do these things, do them quicker, do them better, look at more options and alternatives are all here.

But the big revolution is going to be the interfacing of the software in the computer systems within the design office with the rest of the construction team, and right now that hasn't happened. This is where there's really going to be a revolution.

Wendel's doing it because he controls his total destiny. The present design, fabrication, erection and construction process is very spread out, diverse and fragmented. I think the process is going to come together — that's where a lot is going to happen. CAD and computers are obviously going to be a big step in the right direction.

As far as structural engineering of multistory buildings, as far as floor systems are concerned, we really have reached the optimum. We really can't get any lighter than we have with present materials. We use steel. We use concrete. Anybody that's attempted to get it lighter has had floor levelness problems, deflection problems and all sorts of human-perceptibility-to-motion problems. We have, in my opinion, reached the optimum in floor design.

If we take the example of a typical building, a forty-story, high-rise office building, it takes about ten pounds of structural steel per square foot of floor area to support gravity loads. That's the material in the floors and the columns. But it takes a total of about 20 pounds of structural steel per square foot when you get done. The additional ten pounds of steel is to resist wind. If you go sixty stories or eighty stories, the 10 pounds for gravity loads remains fairly constant, but the contributing portion of the steel material to resist wind loadings is where the big weight increases start to pile up.

We could fool ourselves and attempt to make the floor lighter, but if we're going to get much lighter than ten pounds, we will get sued when the floor deflects or bounces too much.

What's interesting is that Wendel's slides primarily addressed roof structures, enclosure structures and the monumental or the architectural centerpiece of a project, which is the exciting part of the project. However, when you look at percentages of area within a building project, probably five percent of the area is in that part, and 95 percent is the floors. So going back to this point of the floors, I'm not saying space trusses can't be used for floors. We're using truss systems in office buildings now because we're up to 45-foot spans. We want to get mechanical penetrations and make it a 'smart' building. There is one major developer, Oxford, from Canada and the United States, who uses truss systems in all its buildings. There's no reason why space truss systems couldn't be used in the same thing.

Trusses allow you to open up an interstitial space in the floor to allow all of the mechanical systems to go through. Unfortunately, when you compare it to conventional trusses and conventional beams, it's still too expensive, but I think it's going to get there. As more people like Wendel get involved and bring this total capability together, I think there are good chances there.

Moving to the wind system and the NASA group, I'll use one example. Around 1965, as we were designing an 800-foot observation tower in Milwaukee, we sat back and said, "The gravity-load-resisting components of the project constitute about 10 percent of the job." It was not an occupied building — it was an observation tower. Ninety percent of the structural material was required to resist wind loadings. But what is wind loading? Maximum design wind loading is a one-in-one-hundred-years mean recurrence interval. We design for a situation that happens once every one hundred years. Now, that could happen next year, which it usually does, but you're putting in 90 percent of the material in a special tall tower to resist a one-in-one-hundred-years occurrence. Why not try a different approach?

NASA, when they move the Saturn V from the assembly building to the launch pad, has a system of servo-mechanism, hydraulically-activated jacks to keep the Saturn V in a fairly vertical position. So we called up General Motors, Delco Division, who did that work, and we asked whether or not it was possible to develop an active system which would sense acceleration, velocity and drift or motion of a tall tower and activate hydraulic jacks in the building connected to cables that extend from the top of the tower to the foundations. So when the building moves, accelerates or displaces, these jacks activate and the building is brought back to a vertical position.

Obviously, the concern is that the system could go out of whack and go in the opposite direction. Because, if the building is moving away from the wind, you want the activated jack on the windward side. If it's jacking on the leeward side, you've got a problem since it will magnify, not reduce, the movement.

Delco came in and priced the system, and confirmed that it was totally reliable. This was 1965. We've come a long way with home computers and other sophisticated control systems since then. My feeling is that this active system approach in taller buildings, to eliminate the need of putting 50 to 90 percent of the material into the building to resist a one-in-one-hundred-years occurrence, is probably an area that people should be looking at. It can be done!

The Citicorp Building in New York City and the John Hancock Building in Boston both have tuned-mass dampers at their tops. Now, these are not active systems. they are really passive systems because they sort of lag behind and slow down the motion of the building. In the mechanical machine design area, tuned-mass dampers have been prevalent for years. A tuned-mass damper is a device that stops vibration. It vibrates out of phase with the building and slows it down. It works in buildings, although it is not really an active system. I think that is one area in which major innovations are going to develop.

Another way to try and do something technologically advanced is to reduce the amount of material in a high-rise building by doing what the home-building industry has done with the use of stress-skin plywood. Stop and think about it. There's no wind analysis done by an engineer on a one-family residence building, right? Wind stability of a one-family residence is inherent in the adhesion of the plywood through nails or glue to the stick-built system. Until the plywood is put on the building, the frame is sort of flexible. The plywood forms a stressed skin.

Well, the skin, using Professor Tucker's figures, becomes one of the two major cost components of a building, along with the structure. If we can integrate the skin or enclosure into a structural system, we can achieve real economy.

We tried it recently on a very successful project in Pittsburgh for U.S. Steel Realty. It was nice that we were working for U.S. Steel Realty; they encouraged us to use an exposed steel solution. It's a fifty-five-story building. It was called the Dravo Building, but then it became the Mellon Bank Center Building. It uses a quarter-inch-thick steel facade. It's the architectural skin with the windows mounted in it. But it's also a valuable part of the structural system. Without it, the drift of the building is double the magnitude that we deem acceptable by human perceptibility acceptance standards. With the stressed steel skin, the movement is reduced to one-half the magnitude.

We have an internal skeletal structure of columns and beams which safely resist wind from a stress point of view. However, the drift at the top of the building would be 36 inches (H/250). When we put the one-quarter-inch-thick steel skin on, it acts as a stressed-skin, and we bring the drift down to 18 inches (H/500).

We ran into an interesting problem in the process. Exposed steel is not fireproof. So we went to the Pittsburgh Building Department and convinced them that the chances of a fire totally enveloping the entire exterior skin on the building were quite remote. By the time that happened, if it could happen, the building would be unoccupied, and if the drift were twice what we felt was acceptable by human perceptibility, there'd be nobody in the building to perceive it anyway, so they accepted it.

It's a new concept. It's a concept of safety versus human perceptibility and comfort. Codes do not prescribe any drift or any acceleration controls. There are no human perceptability limits on controls within the codes. The codes only address safety.

Both the use of an active system and the integration of the exterior skin in the wind drift control system are areas where I feel the building industry will make major revolutions in the design and construction of taller buildings.

Fireproofing. The steel industry has been wrestling with this problem for years, but if someone could come up with an inexpensive, thin, easily applied, durable fireproofing system for structural steel, I think you would see a major revolution in construction.

The aerospace industry has developed intumescence paints and sublimination coating materials. They're still too expensive. They are available, but somebody should try to develop a low cost fire-proofing coating system that is architecturally acceptable. This would change a lot of what architects do in terms of structural expression. It would eliminate all of the materials that get sprayed on after which everybody spends millions of dollars trying to cover them up so you don't see them. Some of the already available materials, particularly some of these subliming paints, actually look like an enamel finish. They're excellent, but too expensive.

Let's jump to materials. Steel and concrete are the two major structural construction materials. I have attended a lot of meetings with many people who try to introduce composites (fiberglass, boron, and graphite laminates) into the construction industry. The reason it's not coming in, besides the other reasons that Al mentioned, is that concrete costs only six cents a pound; people lose sight of that. It's probably the cheapest, most abundant material around, and steel at 60 cents a pound, fabricated and erected with its strength ratio between concrete and steel is about one to ten is also a bargain. Concrete is six cents a pound; steel is 60 cents a pound. So you use ten times as much concrete at one-tenth the price, and as Professor Tucker mentioned a minute ago, when you run out the numbers in most major cities and you look at the concrete and the form work versus the steel and the metal deck witn the concrete, they both come out to be $6.00 to $8.00 per square foot. They're competitive. You can't get it any better than that, and so I don't see much revolution happening in the area of structural systems unless the new material's cost can be reduced.

We, on occasion, have ventured into the development of esoteric materials for structures.

We usually end up getting very frustrated and disappointed with the result. About twelve years ago we developed a paper bridge for the International Paper Company. It was meant to be a television commercial, but we found the material to have fantastic potential. Paper is a marvelous material, and we thought it had fantastic applications for concrete formwork and disposable formwork. You can make it waterproof, you can make it fireproof, and it's stronger pound for pound than concrete. It's basically processed wood when you think about it. It has never caught on as a construction material. The paper industry never caught on to it, but there's no reason why paper in a honeycomb, cellular-type system could not be developed as a formwork system for concrete. It just hasn't happened to date.

We've found that most new developments in the area of materials occur in what I call adaptive use of off-the-shelf items. It's probably an area that should be looked at futher. A few years ago we designed and engineered several superbay hangers for American Airlines in California. Each building held four 747s. We took an H.H. Robertson or Inland-Ryerson type cellular electrified deck for a typical office building floor and applied it to a hyperbolic paraboloid structure. We used simple spot welds. It worked marvelously. This 230-foot catilever structure had only about ten pounds of steel per square foot in it. We were supposed to build eight of them. We only built two, and no one has done another one since.

In order to achieve this innovative structure, we had to deviate from normal practice. The process was brought together. We were the engineers. None of the contractors wanted to analyze the erection schemes; so we analyzed the erection schemes. Nobody knew how to maintain the quality control on the part of the contractor; so we set up the contractor's quality control manual. We stuck our necks out relative to normal responsibilities and it worked.

There is a great tendency toward fragmention and diversity in our industry. I think the whole role of the designer and the constructor has to be redefined. There have been many recent conferences, papers and hearings about designers (architects and engineers) skirting their responsibilities relative to design of steel connections, for example.

There are hearings going on in Missouri right now to try and revoke a structural engineer's license for the Kansas City Hyatt collapse. The engineer is saying it was the contractor's responsibility. The contractor is saying it was the engineer's responsibility. When you go and look at the American Institute of Steel Construction (AISC) specification in depth, you find that it's really very confusing as to who is really responsible.

What has happened is, although engineers and architects have wanted to get more involved in the construction process, their insurance company, lawyer, ASCE, AIA, ACEC, and everybody else involved has said, "You shall not be involved in construction means and methods. You shall not be involved in erection sequences. Stay out of it. Don't use the word 'approved'. Don't get involved, and keep it fragmented."

Well, in spite of this approach for the last twenty years, there are still too many problems and too many lawsuits. I think what's happening is the ACEC, ASCE and AIA are starting to come back and say, "I think that the designers have to play a bigger role in the construction process." Futher justification of more involvement is in the fact that one-third of the project cost relates to an interim financing cost. Designers should get closer to the construction process through their computers (CAD) and link the design to the construction by taking contract documents and converting them into mill orders and shop drawings (CAM) to bring the whole process together. That's really where the big savings can take place.

Here are a couple of examples. Turner Construction Co., on a $80 million Westin Hotel recently built in Boston, decided they were going to slip-form the concrete core of the project. No one had ever done it before in Boston. I told them I thought they were crazy because of the difficult local trade jurisdictions and strong unions in Boston. But they decided they were going to take a crack at it. They brought the unions into the picture early and made them part of the process.

Since Turner was involved as the construction manager early in the game, we, as designers, agreed to use a slip-formed core. We also agreed we would use a flying-form system, and we would design the precast facade so that it could be incorporated into the flying-form system. So when the building form went up, the precast pieces went up with it, and when they poured the floor, they inserted the windows, and in record time they had an enclosed building so that the other trades could come in and work on the remaining systems within an enclosed, heated environment.

Had we not worked together on the approach in the early stages, it would have been a much more conventional building. We got involved in the process and it paid off for the project.

Olympia & York, the developer of the World Financial Center at Battery Park City in New York, tried to apply what they do in Canada to New York. They deserve a lot of credit — they got halfway. What they did is interesting. They incorporated the material-handling systems that are needed during the construction into the basic design of the building. The elevator shafts are sized so that all materials go up and down inside the building, not on an exterior materials hoist.

For a conventional project, we never know in advance who the contractor will be. As a result, we don't bother to try to accommodate the design to facilitate materials handling to be facilitated. Do you know what the cost of a lift on the outside of a building is? With post-modernist design solutions, with setbacks when you get up to the sixtieth floor and you've got to get over 60 feet to reach the exterior wall (how do you get it from here to there?) it's a big problem!

So the recent tendency to have buildings with setback tops could swing us more to central materials-handling systems. It is obvious that construction managers and general contractors as well as designers have to be more involved in that total process. This will save time and money.

In summary, I think in the immediate future further impacts will be in the area of computer usage; integration of various building systems; the exterior walls and the structure; gradual acceptance of new materials; and a whole change in the delivery process. Big changes are going to result from these impacts.

The other obstacle is the impediments, which everybody has talked about; unions, special interest groups, codes, jurisdictions and, from a designer's side, fear of litigation. It's gotten to the point where most, if not all, of the United States' design industry is not innovating any more because of fear of litigation. It really doesn't pay to innovate any more, because the chance of getting nailed, in our litigious society, is almost predictable. There may not be too many attorneys in Japan, but there are too many attorneys and too much litigation, too many frivolous lawsuits against the practice of architects, engineers, medical doctors, etc., in the U.S. today. This aspect of our industry is hurting the advancement of, and innovation with, the American design and construction industry.

Dr. Charles H. Thornton is President of Lev Zetlin Associates, Inc.

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Over the Horizon
Raymond P. Whitten

Raymond P. Whitten

I'll begin with a review of what NASA is doing in Technology Utilization; and then discuss some of the complications of technology transfer. The infusion of technology into our society is very difficult, and I will give some examples of the impediments. Nothing happens through serendipity. The process is "people intensive."

Even though NASA technologies may be useful to the building industries, it's going to take work to couple that technology with industry needs. Our program works with industry and the user community. We do not unilaterally develop prototypes and certainly do not do commercialization or marketing.

NASA can learn a lot from the progressive building industry's thinking in terrestrial applications. This will be evolving as we move into Space Station and Lunar Exploration. NASA has a system in place that is both a paperwork and a 'hands-on' people-to-people process. We have developed ways to disseminate technology as it is documented through a Scientific and Technical Information Center and have provided for a Computer Operated Software Management Information Center (COSMIC). This systemcan be tapped by industry, U.S. citizens, state and local governments and universities at any time. Both information and computer programs coming out of NASA and other federal laboratory programs are available through the system.

The Applications Engineering Program is people intensive. It's in this program that we identify and define user needs. Once the problem is fully understood, our scientists and engineers try to match NASA-developed technology to the problem. If there is a match, a working partnership is developed between the user and NASA. If a successful match is found, industrial or business development leads to marketing and commercialization of the technology.

Our network is located around the various NASA Centers. It consists of the Industrial Applications Centers (IAC's), COSMIC and a Technology Applications Team. The system serves industry and the public by providing information, retroactive technology searches, and 'hands-on' assistance in problem solving. There are some small fees involved for IAC and COSMIC services and a required commitment of funding in application engineering. The Industrial Applications Centers are kept current on evolving NASA technologies through the various NASA Centers and/or laboratories. Evolving technologies are summarized or documented in various NASA publications. Some of these publications are called NASA Tech Briefs, Annual Technology Utilization Reports, NASA Patent Abstracts, Research and Technology Operating Plans, Special Publications and Technical Memoranda, Scientific and Engineering Journal Articles, etc.

Transfer of technology from these programs to the building industry or anywhere else does not happen without a lot of elbow grease, technology 'know-how,' motivation and support from upper management. All NASA technology that eventually ends up being used for nonaerospace applications must go through some form of adaptive engineering in order to satisfy the needs of the new problem. I have yet to see a one-to-one transfer, i.e., a situation where the aeronautics or space technology can simply plug into the new application without some form of modification.

Examples:

Several new technologies can be applied to fire protection. For instance, we have used NASA turbo-pump technology to develop a new water-pumping system with a flow of 3-5 thousand gallons per minute at 150 psi. Acceptance of this technology has been slow even though it is badly needed. Conversion to this type of equipment requires new thinking in the fire-fighting community. It requires training and an expensive marketing effort. The fire-fighting module, as we call it, can be lifted by helicopter and placed almost anywhere — cities, rural areas, forests, aboard ship. In addition to its use in fighting fires, it can provide drinking water to ports serving countries facing severe drought, or even used to salvage oil in areas where spills have taken place at sea.

The power-factor controller, which I'm sure all of you have heard something about, was developed conceptually within NASA. It is now found in industry and large buildings. It is even used in energy management of escalators. This system is based on electronic technology available today throughout the industry. It took the creative efforts of an aerospace engineer to conceive and develop the concept.

Several years ago NASA and HUD worked together with some aspects of the building industry to develop the NASA Tech House at the Langley Research Center. NASA is pretty good at systems engineering. In the case of the Tech House we demonstrated how one could systematically develop an energy-efficient house using state-of-the-art and innovative technology. To evaluate the concept, the Tech House was literally wired for sound, similar to the way we would technically monitor the performance of a new experimental vehicle. In fact, we are still monitoring, collecting and evaluating data. The data that NASA collected pertained to operation of solar collectors, solar panels, electronic systems and water management; it was analyzed for efficiency, reliability and maintainability.

The Flat Conductor Cable is an example of how difficult it is to bring new technology to the building industry. It has been about twelve years since the concept of transferring aircraft and space vehicle flat conductor cable to the building industry was tried. NASA developed the technology to save weight, space and energy. It is just now becoming available, for non-aerospace use, as a marketable product. For retrofitting or remodeling homes, offices or factories, it offers a fairly simple solution. For new house design, it could be integrated with composite materials to develop new concepts for modular and mobile wall structures. Improvements could be seen in outlet placement and energy management.

As you know, NASA is confronted with water and waste management problems in aircraft and spacecraft. Reuse of water will be especially critical in future manned space missions. Future concepts and resulting technologies are becoming available and could be applied to the building industry. Why build on our best and most fertile land when water and waste management systems provide alternative solutions. The extreme is to take waste or gray water and make it safe and potable drinking water. Gray water can be recycled many times for wash water. Energy and land management conservation methods can be employed if one is willing to apply the technology and change traditional ways of doing things. Some of these concepts have been demonstrated in the NASA/HUD Tech House; however, the concepts are not being rapidly adopted or put into practice.

There are several technologies that are on the horizon and will be seen in the near future. The REDOX energy storage system, which is an oxidation reduction system, is representative of such a technology. The NASA Lewis Research Center and the Department of Energy have been working on this technology for many years. The idea was derived from the fuel-cell technology developed for U.S. spacecraft. Essentially, this is a type of battery storage system that is going to become available and marketable in the near future. In order to transfer the technology, NASA is working with SOHIO. SOHIO is investing in a demonstration program that will eventually lead to small community, industry and, perhaps, individual home use of the REDOX technology. Imagine a community that is using the REDOX system; it stores its energy in a cost-effective manner and offloads it or sells it back to the power company as opportunities develop. The key to the system is a reduction/oxidation system with soluble liquid electrodes which make energy requirements independent of power demand.

Another evolving concept is the Magnetic Heat Pump. This technology is based on the fact that certain magnetic materials discharge and absorb large amounts of heat when strong magnetic fields are alternately applied and removed. In theory, the ideal magnetic cycle is more efficient than the ideal evaporation cycle that utilizes freon for refrigeration and heat pumping. Heat transfer considerations suggest a superior efficiency for magnetic pumping and analytic studies predict lower capital cost for machines above 50-100 kW cooling or heating power. The higher predicted efficiency of magnetic cycles would have a favorable economic impact through lower operating power requirements, and considerable fuel savings, in a wide range of applications that includes heating and air conditioning, industrial process refrigeration, air separation (for steel plants), and heat pumping for process heating.

Heat pipe technology, one of the first real examples of practical applications of this technology outside of the Space Program, is seen in the Alaskan pipeline where it controlled the permafrost in the ground. All spacecraft tend to use the heat pipe technology to control, balance and maintain desired spacecraft internal temperatures. This management of solar energy and heat pipe technology is now finding its way into domestic use. Today, the Kennedy Space Center is working with several companies in hopes of using this technology for home, office and/or large building air conditioning systems. It is speculated by some that future homes may effectively use heat and electricity that is derived from solar energy, ground heat, heat and electrical storage systems and heat pipes. The heat pipes will allow heat to be moved from place to place while sophisticated battery systems will accommodate electrical energy storage.

The future holds a promise for new techniques in structural analysis, nondestructive and non-invasive testing of materials. At the Langley Research Center a major effort is underway in ultrasound technology. Here, instead of looking at the torque stress in bolts, the torque on the bolt is viewed as friction. NASA scientists are looking at the elongation of the bolt and the resulting stress. The Langley scientists have been so successful in demostrating this concept that the Space Shuttle, U.S. mines, aircraft and other systems requiring bolts as fasteners are applying ultrasound as a noninvasive stress tester. There could be many applications of this technology in the building industry.

Earlier we discussed robotics and automation. NASA is not the leader in new robot or automation technology, and it doesn't plan to be in the future. NASA can help U.S. industry move ahead in automation and robotics by exploiting its specially developed sensing, computer, image enhancing and display technologies. At the NASA Jet Propulsion Laboratory, NASA and industry are working together to transfer some spacecraft sensing technology to develop 'smart robots.' These robots are being developed to have enough visual image information to see edges and corners and adjust accordingly. The technology stems from highly specialized integrated circuitry, chips, proximity sensors, microprocessors, etc. The technology transfer here is not the robot — it is the special components that the machine needs in order to respond to the environmental challenge.

There is also pultrusion technology, and CAD/CAM systems that can be applied to the building industry. The concept is similar to that described as evolving in Japan. The idea is that you program what you want and, based upon your computer design, the automated machinery provides you with studs, wall panels, doors, shingles, 'I' beams, etc., all to the precise stress and other measurements you call for in your building design. Plasma-coating material has potential for future applications of glass materials and ceramics. The plasma coatings that were developed for the astronauts visors to prevent scratching and fogging are now being applied to windows and sun glasses.

The crystal and other types of materials that are going to be developed in space may have an application that allows for greater automation and computer power. Future energy systems may become a magnitude more effective than they are now, which will allow for smaller, smarter, and more powerful tools that require less energy, less time and maintenance, and help mankind work with greater precision and safety.

The Programmable Implantable Medication System or PIMS might also apply to the building industry. The outer case for the PIMS is made out of titanium, developed for the aeronautics industry. The internal working parts of the PIMS are electronic microprocessors. The microprocessor in this device is approximately equivalent to the IBM-1050. It can operate over fifty color TV sets. It can program microliters of medication into the body as prescribed by the physician. The physician can reprogram the PIMS anywhere in this country, or in the world for that matter, as long as he has a phone modem between the patient and himself. The concept is based on our satellite and telecommunications capability. The electronics technology is derived from our spacecraft and satellite technology while the fluid management system comes from the Viking lander that landed on Mars and tested the Martian soil for life forms. Imagine a device the size of a hockey puck implanted in the body providing biological functions through microminiaturization of many component parts that would have taken the space of a ten foot by eight foot by two foot thick wall only fifteen years ago.

Now, what I'm saying here is that none of the technology that has gone into this system could have been applied without taking the time to understand the problem and applying imagination and technical 'know-how'. There is a lot of space technology that is unused; many applications could undoubtedly be made for the building industry. For example, the concept of infusion pumps has been studied and developed for medical use during the last several decades by the National Institutes of Health. Working with the Johns Hopkins University, the National Institutes of Health, and industry, the PIMS represents several years of time compression since the total development took less than three years. The cost to NASA was $1.6 million over three-and-a-half years, while the industry investment will exceed $30 million (estimated) to place the device in the market. In this case, the government was the catalyst as it stimulated a business opportunity by using unrelated technology to address and solve a complicated problem.

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Reflections on the Presentations

John P. Eberhard
James Gross

John P. Eberhard

Our purpose here is to anticipate how technological change will affect the building industry either from the supply side or from the demand side and to determine whether any of these changes could create problems that Congress ought to be aware of and, potentially do something about.

A. The Six Construction Industries

Here in Washington we often choose to talk about the 'building industry,' and discuss issues like changes in the levels of employment, changes in quality and safety, changes in productivity, changes in opportunities and risks from foreign competition, as if it were a single industry. I don't think this makes much sense.

In many ways the building industry is no more monolithic than the transportation industry. The transportation industry includes the airlines industry, the railroad industry, the trucking industry, and the shipping industry. There is little crossover between the organizations, the institutions, the skilled manpower, the technologies, and the R&D base that are utilized by those sectors of the transportation industry.

Practically no Federal policy can affect each of the separate industries within transportation. But since you don't want too many units that report to the President, you can create a Department of Transportation and lump all of those things that have to do with movement under it. It also is useful to talk about a transportation industry for economists who want to make measures of the national economic sectors. It avoids having that many more pages of statistics if you can somehow or other have a number that represents the contribution of the transportation industry to the gross national product.

The building industry, or the building industries, as I prefer to call them, are combined for much the same reason. It makes sense to look at the several building industries if what one wants to identify is expected changes in the industry.

For our purposes, it seems to me there are six industries which react quite differently to those kinds of issues:

- The first is the *housing industry* — the collection of organizations, technologies, skills and financial mechanisms whose purpose is to convert raw land, usually purchased on a speculative basis, into dwelling units that can be sold or rented to individuals and families. The major distinction for the purpose of analysis is that this process is begun before there is a buyer in mind. The builder of these houses builds a house against a potential market, not against clients who come to them and say, "These are our needs, and we want a house of this kind." Very few houses in the country are done that way, and I put those in the fourth category.
- The second is what I call the *manufactured building industry*. I call this a separate industry because it is a collection of organizations, technology, labor and financial mechanisms whose purpose is not to convert land into buildings, but rather to manufacture off-site units that are anywhere from the whole unit to subassemblies, which can be transported to the site. A few companies like the Ryland Corporation own house manufacturing capabilities, as well as build conventionally, and I'm sure we can find all kinds of exceptions at the margin for each of these.
- The third industry I call the *commercial developers*. I mean by this people who buy raw land and convert it into buildings other than housing — people who develop industrial parks, people who develop shopping centers, or people who develop office buildings. Again, the character of this industry is that there is no client in advance. There's a prospective market out there, and there's land, and there's an investment to be made in building something on this land which will eventually be leased or sold to a set of users which will emerge.
- The fourth industry, is the one that most of us

think about when we talk about '*the building industry*.' It is the conventional collection of organizations, design and engineering firms, banking institutions, general contractors and subcontractors, regulatory bodies, etc. that build buildings for specific clients: an agency of the Government, a private client, or sometimes a wealthy family. The client sets the requirements, decides on where they're going to locate, usually purchase their own land, and then enter into a process in which a design is created for them that's eventually put out to competitive bids. The 'building industry' listed here is the only industry in which competitive bidding occurs. It is practically the only industry of building where there will be a major change if there is a technological breakthrough. It's the one building industry where bidding can reflect market conditions as a result of changes in prices.

None of the industries listed above really have much competitive bidding. Sometimes market competition works in the housing industry, but only over a long period of time. The major impact of the housing industry, as we've mentioned already this morning, is what it cost to buy the land, and what is the mortgage rate that they have to pay? We used to speculate we could practically build a house for nothing, and it wouldn't change the price which people would pay for housing, because the market price for housing was determined by a whole lot of factors other than the technology of building.

- The fifth industry, *the remodeling industry*, is one we sometimes forget. Of the $250 billion that represents our 10 percent of the gross national product, is included almost $50 billion in this remodeling industry. This probably does not include rehabilitation of existing buildings in the sense that an architect and contractor might do it, nor does it include rehabilitation of the kind that homebuilders do. It means the remodeling industry that sells things from aluminum storm sash, to screen doors, to new store fronts for small businesses; that is financed by short-term financing rather than increases in mortgages. It is not regulated by building codes, by and large. For a long time, it could be characterized by the blue suede shoe type of salesman.
- The sixth industry, and the one that OTA chose not to cover in this workshop, is what I call the *heavy construction* industries. These industries build highways, dams and facilities. Their clients are primarily public agencies and utilities.

I can make a couple of statements about these six industries that are useful even though there are exceptions to everything I'm about to say. First, the fourth industry in my list, 'the building industry,' is the only place in which technological change has a dramatic and immediate impact.

Secondly, if one tries to make a definition of an industry which is a collection of people who represent a common interest because they supply a common concern, these definitions hold up pretty well. One of the ways that is very visible if you work in Washington, is by seeing who is it that lobbies. And the people who lobby for each of these groups don't really concern themselves by and large with the other groups. People who are lobbyists for the housing industry are not, by and large, concerned about the commercial developers or the remodeling industry or the heavy construction industry, and vice versa.

Also, another way to look at it is who supports the R&D and where is the R&D done. A few universities do research that crosses over these industries, but if you look at the individual in the university who is doing research, their research is oriented towards one of these industries, as contrasted to the industry across the board. I also think that there are very seldom movements of companies, of skilled labor, or even of financial mechanisms across these industries.

The prospect, therefore, is that when we talk about the impact of technological change, as OTA will be doing, and what that means to the building industries — and we provide advice to policy makers like Congress about what can be done about looking at the impact of technology on the building industries, that if we are being as clear as we can be about it, that we mean there are these six industries and not one industry.

B. Evolution vs. Revolution

We must also be clear about the nature of the changes now underway in the building industry. We're in an industry in which the character of change has been evolutionary and not revolutionary, and that's likely going to continue to be the case. A lot of my fellow executive directors here in the National Academy of Sciences are responsible for areas that have only been around for ten years or fifteen years. Some, like chemistry or physics, have been around for over one hundred years. But we've been building buildings for over five thousand years. Over that five thousand years inventions and innovations have been introduced, primarily by trial and error.

When we have an industry like the electronics industry, the mean time between surprises is zero. One expects a new surprise to come out of that technology practically every day, but it was born in a period of time when the kind of race that it's running is equivalent to the 100-yard dash. The pace of change in the building industry is more appropriate for running in a 26-mile marathon. You don't use the same techniques in the 26-mile marathon that you use in the 100-yard dash. The construction industry has learned what works, what doesn't work, and how to bring about change very slowly.

Well, what is a revolution? And if we were to try to describe to Congress whether there are revolutionary changes possible, conceivable, or likely to happen in this industry, what would we mean by 'revolution' as contrasted to 'evolution?' There's a simple definition of 'revolution' for this purpose. By 'revolution' one would mean the rapid displacement of an existing set of ideas or skills or institutions. That is, somebody would be out of business who's now in business, or some idea would be out of vogue that's now in vogue, and a new idea, a new set of skills or new set of institutions that were considerably different, not just slightly changed, would have come into existence. Technology has created many 'revolutions.' Consider the field of medicine. Practically no child has measles today. Diphtheria has been eliminated in the world, not just in the United States. Literally in the world there are zero cases of diphtheria at this point. Technology is transforming the office. I learned to type when I was in the service. But the word processor is so much more convenient than the typewriter that the typewriter is practically useless to me today. I wouldn't want to use a typewriter, as such, even though there are new typewriters still coming out on the market.

Tower cranes are one of the technological changes that were introduced into the building industry that displaced old concepts, and I gather the tower crane may, in turn, be displaced in the near future.

Well, what kinds of things have we talked about in this workshop that have the quality of revolutions? I thought I would concentrate on those since evolution in this business, after five thousand, is relatively easy to deal with. Maybe some of us believe there needs to be some ameliorating consequences on the part of Congress, but by and large, I'm impressed after twenty-five years in Washington that in our society, we do adapt to evolutionary changes. We're less good at, less clear about how to deal with revolutions.

So what kind of revolutions might be coming out of what we've talked about, 'revolutions' meaning the displacement of an idea that's in present currency, the displacement of a set of skills or the displacement of a set of institutions?

The clearest, most easily understood, example is what I would sum up in the word 'telematics' the combination of electronics that combines communications, computers, electronic controls, et cetera.

In Harry's report on the first day, and Alton Bradford's as well, most of us are made aware of the fact that telematics is dramatically going to change the building process. This is conceivably revolutionary in the sense that there will be displacement of skills in professional firms as a result of this telematic change.

Every time in history when somebody is getting too much of the pie for themselves, some kind of revolutionary change occurs. New institutions come into the business, and those new institutions create a different way of doing things. I think that one-third cost now of buildings that does into money might, in fact, precipitate not only a change in time, but a change in the way money enters into this system.

Then finally the lesson that comes from NASA, that Stan talked about, is that the largest single invention in our lifetime has been the invention of how to invent. For the first time in history we can purposefully go about inventing whatever the mind of man can conceive. That's never been true in history before.

How we go about invention is the key. What we did not do when we decided to go to the moon was to hire an industrial designer, an aeronautical engineer, and interior decorator and a couple of other professionals and say, "Design us a spacecraft that we're going to send out for bids." Why didn't we? Because the big secret of invention of invention was how to use ignorance as a resource. How to find out what it is we don't know. That's what the space program has taught us; how to systematically go about finding out what we don't know. Work on a collection of things that you don't know until you do know something, and you can release a new set of discoveries.

I think we're in the building field with telematics now at a stage where we may produce a revolution of that kind, a new set of characters who will say, let's systematically go about not just new product development, but new concept development by using ignorance as a resource.

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James G. Gross

I will address the needs and opportunities of the building community as I see them. I will briefly address opportunities as they relate to computation and automation, education of professionals, productivity, and building research. Suggested will be a model for change that might be given some consideration.

On the subject of automation and advanced computation, it's amply evident to all of us that this technology is coming on like gang busters. The work that Wendel is doing in the design and manufacturing of space frames is extremely advanced. But we must be impressed with the fact that it's still fragmented. The hardware, the software, and the languages still don't interface. Wendel showed that he had to bring the architect to his office in order to communicate. The day will come when he, through his computers, will be able to communicate directly with any of his clients, and his clients with their clients and consultants. Expert systems have not yet received much attention, but the opportunities for expert systems will put new demands on architects, engineers, and researchers.

We continue in a construction process that regenerates the same information over and over again in spite of the fact that we have this wonderful new capability in front of us. Basic information about the building is generated at the predesign or programming stage. It's regenerated at the design stage, not ony by the architect, but by each of the involved consulting engineers.

For example, an architect will develop the necessary information to design a wall system. The mechanical engineer again will develop some of the same information to calculate heat gain and heat loss through the walls. The structural engineer will need some of the same information to determine the loads on the foundations. Then the contractors bid the job. They take off much of the information from the plans and put it into their computers to prepare bids. The building regulator, who has to check the plans for compliance with the building codes, does it again; maybe not to the same depth, but he needs to look at the plans that relate to safety characteristics such as fire resistance. Over and over again, the same information is regenerated, each time increasing the chance for errors and decreasing overall productivity.

The contractor, after receiving the award, has to take the information off the plans and specifications in detail for ordering the materials and scheduling the work. The fabricator extracts the same information to develop shop drawings. Yet, when the project has been completed, the previously developed information is not available to the owner and occupants who need it to operate and maintain the building. Nor is it available to those who want to rehabilitate or demolish the building.

We need to develop the necessary interface standards which will allow the various proprietary hardware and software systems to talk to each other. We should develop these standards, using the voluntary standards organizations now in place. This will permit all affected parties to have an input and a part in the development of the standards.

Research needs to be conducted to obtain knowledge on the application of artificial intelligence to the development of expert systems for construction. In the area of education for professionals, we have been told — it was said over and over again during these past two days — that tomorrow we're going to have to work differently, architects, engineers, and constructors will need to work as a team. Nevertheless, today we still see much fragmentation at the university level. For example, mechanical engineers usually don't learn much about building technology as part of their education. They may be in the same building, but they don't talk to the civil engineers, and the civil engineers don't talk to the architects even though they do most of the structural design. Electrical engineers usually don't show much interest in buildings, and the architects are off in their corner, concerned primarily with drawing and the aesthetic aspects, not the technical issues of buildings. Many builders and contractors are educated in schools where business management is the matter of primary concern.

If we look at the recent past, you will see that architects have enjoyed relatively less of the design fees paid for building design and construction; and their proportion is decreasing. Engineers, on the other hand, because they are applying more technology, have experienced an increase in their part of the pie. The time has come when many firms refer to themselves not as AE firms, but as EA firms, which was almost unheard of ten years ago. This indicates an increased emphasis on technology applied to building design practice. I think it's time that we look at the opportunities to educate this team as a whole. There are big potential payoffs by studying and improving the way we educate young professionals so they can better work together as team members.

The next item I want to touch on is productivity. I was interested in what Dick Tucker said about increasing productivity at the job site, but I want to address the subject from a different angle. We were told yesterday that the environment in the 'smart' office building can increase productivity 24.9 percent. That is a very impressive number. Michael Clevenger made a convincing argument that we can increase productivity by that amount. Let's look at the meaning of increasing the occupants' productivity, not just the typing pool's production of typed pages; but let's see what it really means in dollars.

Several years ago we provided technical support to the General Services Administration for their building systems program during which we looked at the life-cycle costs of a building from a productivity viewpoint. When we looked at the life-cycle costs over an office building life, the numbers came out something like this. The initial cost to build an office building is in the order of two percent of the total cost to build, operate, and product in it over a life time. Approximately 6 percent of the total cost is for operation and maintenance, and 92 percent is to pay the people who work in the building.

So let's extrapolate from these numbers and look at what an increase in worker productivity can mean in the total scheme of things. Even if you add an additional 25 percent to the initial cost of the building, in order to increase the productivity of the people in the building by even 10 percent (e.g., reduce labor costs by 10 percent). You would get a return of 18 times the investment. I know of no other investment as financially attractive today; and if you achieve the suggested 25 percent increase in productivity, you get a return 46 times its cost in present worth dollars. Those kinds of investment opportunities are unheard of. We ought to be looking at the impact that a more productive built environment could have on the construction industry, the opportunities for architects, engineers, building materials and equipment suppliers, developers, and investors. We need to look at this opportunity for all types of buildings, from office buildings to the factory floor. What would increased productivity mean in educational facilities, on one hand, and retailing, on the other hand?

I support a thorough study, including behavioral research, to understand the impact of acoustics, lighting, thermal comfort, air quality, space relationships and aesthetics in buildings as those qualities affect productivity. Such research may be a major opportunity for the construction community. Also a hard look at the influence of the built environment on productivity would be a great opportunity for the country to improve productivity.

A number of papers here argue the need for more research. Research money will usually be available when the financial opportunity justifies the investment, and when the results of that research accrue to the people who make the investment. Yes, then there is money available.

But there is not money readily available to conduct research in which the benefits accrue to society as a whole. There is need for more research support as part of education for building professionals. Other countries are spending a lot more money on building research in proportion to their populations. I don't think they have better ideas than we. Foreign governments are spending money directly on generic research which I mentioned before, and they are providing incentives for proprietary interests to encourage research.

The Japanese private entrepreneur has a lot more incentive to do research than does U.S. Homes. We heard yesterday that U.S. Homes does no research. Individual Japanese construction companies have building research capabilities camparable to what we have at the

National Bureau of Sandards. Some individual Japanese companies have two hundred professionals doing research. When that knowledge hits our shores we're going to feel it more than we do now. Canada is spending a lot more than the U.S., and they are doing a lot more to transfer research results into practice. Also, research has a tremendous influence on quality education. If we're considering improving the education of our professionals, we need to consider supporting research in the same universities.

Mr. Kelly mentioned three large industries in his introductory remarks. The three largest industries in this country are health care, food production, and construction; each approaching 10 percent of the GNP. The health care industry, through the National Institute of Health, has an annual appropriation from Congress over $4 billion; and yesterday we heard about the wonders that are taking place in that area.

Look at agriculture. That is the one industry where nobody in the world approaches the U.S. in productivity and efficiency. The U.S. population is fed efficiently and effectively with the best quality and widest variety in the world. We export more agricultural products than any other product area. The Department of Agriculture spends about $1 billion a year on research.

The construction industry is about the same size as these other two sectors, and spends in direct appropriation at a national level of $8 to $9 million. In addition, NSF supports some building related research in universities; HUD spends a little money for building research; but there are not sufficient monies spent on generic building research in the United States.

Let's look at these numbers. Health care is supported at a level of over $4 billion at NIH, and food production at approximately $1 billion at the Department of Agriculture. Construction represents only one-half of one percent of what is spent for research at NIH. I am not suggesting building research should be at the same level, but I am suggesting that there are excellent building research opportunities that need support.

There are other needs. There is the need to effectively implement findings to improve building practices. John Millhone talked to that point yesterday when he said we know a lot about energy conservation and its use, but we need to transfer that knowledge to the local level so that it's used in rehabilitation.

It would improve our competitive position worldwide if we would develop more new construction technology and transfer it into practice. Let's examine our country's successful model, agriculture, which I mentioned just a minute ago. The Department of Agriculture has a program of national research. There is support for research at the land grant universities in every state. There are related educational programs, and there are technology transfer specialists, called county agents, around the country that move the results of that research into place.

I think we ought to look at the USDA model to see if it might apply to research and education for construction that would offer enormous benefits to the Nation.

I have a couple of additional points I'd like to made. One is that we haven't heard anything about indoor air quality. IAQ is something that's going to get a great deal of attention during the next few years. We don't know what quality of air is required for good health and productivity. We don't know how to accurately measure the quality of air that we breath. So these are two tremendous problems; the first, being health related, I hope the medical profession will tackle. The second is a measurement problem which we in the construction industry can tackle with sufficient support for research.

The other area I want to mention is diagnostics. Diagnostics is needed for two purposes: one, for acceptance and quality assurance of the products and systems we build, and the second is for analysis of our existing buildings, particularly in preparation for rehabilitation. We will see a great deal of good work in the area of diagnostics during the next few years. There's much interest in the research now underway.

I agree with the observations made by others that rehabilitation has been a major growth area and will continue. In order to effectively and efficiently rehabilitate our existing building stock, it's essential that we understand the performance capabilities of that stock. As Eric Dluhosch suggested, it is inefficient and wasteful to gut a building and rebuild the whole inside. What we need to do is to have nondestructive evaluation, diagnostics, so that we can determine what the performance characteristics of that building are so we can maximize the use of our existing resources as we rehabilitate them. There are many opportunities in the areas of thermography and ultrasonics, for example, as well as other NDE technologies. Quality control for new construction and analysis for rehabilitation will require major growth in the development of diagnostic capability.

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